



# Educational design research

Part B: Illustrative cases

SLO • Netherlands institute for curriculum development

Editors:  
Tjeerd Plomp & Nienke Nieveen

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# **Educational design research**

## **Part B: Illustrative cases**

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Credits



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# Preface

In 2007 Professor Zhu Zhiting of the College of Educational Sciences at the East China Normal University in Shanghai (PR China) asked the first editor of this book to organize a seminar on 'educational design research' (EDR) with the purpose *to introduce a group postgraduate students and lecturing staff in China to educational design research as a research approach*. The proceedings of that seminar were written in such a way that they could be used in postgraduate seminars and courses on educational design research. They were published in 2009 as *An Introduction to Educational Design Research* by the SLO, the National Institute for Curriculum Development, Enschede, the Netherlands.

When we met Professor Zhu in 2011, he asked for a number of illustrative cases (15-20 cases) of successful EDR to be used in combination with the 2009-book *with the purpose that graduate students and novice researchers could also learn from examples by others about how to design and conduct a research project utilizing EDR*.

We, editors, decided to take up the challenge after SLO had indicated to support our initiative and be willing to publish the new book. This resulted in a major project (starting in December 2011) comprising not only editing this book with 'illustrative cases of educational design research', but also updating our 2009 book. So, in the end, the project resulted in two books, namely *Educational Design Research – Part A: An Introduction* and *Educational Design Research - Part B: Illustrative Cases*.

Prof Zhu Zhiting and Associate Professor Wang Quyien (National Institute of Education, Singapore) will prepare a Chinese edition of this book for which they will be co-editors .

## Composition of the book

We wanted the illustrative cases to reflect a number of dimensions - as is explained in the Introduction - such as:

- coming from many domains in our field, such as curriculum, learning and instruction, subject related pedagogy (math education, language education, science education, etcetera), instructional technology, ICT in education;
- reflecting various purposes of design research, such as developing an innovative intervention or developing a new instructional or learning theory;
- representing all educational levels (from primary till higher education, and also informal education);
- having been conducted in a wide variety of countries.

As a result, we have 51 chapters covering a variety of combinations of these dimensions as the reader can see from the introduction chapter of this book.

## Unique character as a 'supra-book'

This book is published electronically. But it is also a 'supra-book' with each case chapter separately electronically published, which allows users to make their own selection of chapters given the specific purpose of use – for example, if users want to discuss with graduate students examples of design research in the domain of curriculum development or language/math/

science education, or what design research took place in a certain country or continent, they can select their own set of cases for studying with their students.

The publisher is willing to print the book on demand (and will charge for the costs of printing and handling). But readers are allowed to print their own selection of case chapters provided they follow the copyright rules.

### **Some features of the case chapters**

When we planned this book, an important starting point was that authors should have as much freedom as possible in describing their cases. But on the other hand, as the cases are meant as examples from which graduate students and researchers should be able to learn how to design and conduct a project utilizing EDR as the research approach or design, we wanted that each chapter should address a number of topics that are not only characteristic for good research, but also exemplary for a good case of EDR. We therefore requested each author of a 'case chapter' to address – in addition to describing the chain of reasoning for their research - at least the following six issues or topics (1) Introduction to the problem, (2) Conceptual framework/conceptualization of the study, (3) Research design (for each of the phases or cycles of the project), (4) Assessment phase (if applicable), (5) Yield of the project, and (6) Reflection – lessons learned.

As a result, the chapters included in this book do show a wide variety in structure and style of writing. But we hope that readers will be able to understand how the respective research projects have been designed and conducted, as well as that there is a variety in ways of conducting research utilizing EDR. It is in this context that we want to point readers to the following: it is not always possible to summarize all details of a piece of design research - comprising a number of phases, each possibly with a number of cycles or iterations - in a chapter with a text of maximally 8000 words. We therefore asked authors to focus on those parts of their research that would give a wide audience a good insight and understanding of the design and the conduct of their research. But as we could imagine that some readers would be interested in the details of a particular research project, we asked them to serve those readers by including, on top of the references, a number of 'Key Sources' for the research reported.

### **About the reviewing process**

Obviously, each case chapter has been reviewed by the editors of this book. But in addition, each chapter has been blindly reviewed by two peers of which at least one was not from the same country as the author(s). We also tried to find for manuscript peer reviewers of which at least one had another background than the author(s). See the Introduction chapter for more details on the reviewing process.

Finally, for a period of two months the chapters were placed on a website only accessible for the authors of case chapters allowing them to read these and do an 'open peer review', providing this way feedback to colleagues and/or to include in their own chapters a reference to relevant other chapters. This resulted in some adaptations in a few chapters.

### **Thanks and acknowledgements**

Preparing this book has been a major project. It would not have been possible to accomplish this project without the input and assistance of many people.

The experiment of publishing this 'supra-book' was only possible thanks to the willingness of SLO, the Netherlands Institute for Curriculum Development to assist the project. We are very grateful to Jan van den Akker (Director General) for his support and that of his institute. We

appreciate especially that the SLO was open to embark on the type of publishing that utilizes some characteristics and possibilities of the information society.

We are grateful to all the authors who contributed to the book with great commitment and dedication. We are impressed by their enthusiasm, which resulted in a 'snowball effect' leading to the 51 chapters instead of the intended 15-20 chapters.

We want to express great appreciation and thanks to the colleagues who contributed to the process of peer review – all mentioned at the end of this Preface.

Finally, preparing all manuscripts for publication has been an enormous task. We are very grateful to the support staff of the SLO in taking up this duty in such a dedicated way. We hope that this book will become a source of inspiration and good ideas for many (future) researchers who want to address important problems in educational practice!

Tjeerd Plomp and Nienke Nieveen, *Editors*

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# Introduction to the collection of illustrative cases of educational design research

Tjeerd Plomp & Nienke Nieveen

## 1. Introduction

This chapter introduces the reader to this book with a collection of illustrative cases of design research in education. This section summarizes the background and the aim of this collection of cases.

In 2009 we edited and published the book 'An introduction to educational design research' (Plomp & Nieveen, 2009), the proceedings of a seminar on educational design research (EDR), conducted in November 2007 at the East China Normal University, Shanghai, PR China. In that book, we introduced educational design research as a research approach or research design<sup>1</sup> appropriate to address complex problems in educational practice for which no how-to-do guidelines are available. During the years, many researchers (experts and novices to the field of design research) found their way to this book. Our ideas about how to conduct and communicate about design research developed as a result of our own educational design research studies, the mentoring and supervision of (PhD) students and the many discussions during seminars and after presentations. After five years, we felt the need to revise some parts of the book.

But, maybe more importantly, we also got signals of a growing interest in exemplary case studies of design research that can be used as one of the means to introduce graduate students and novice researchers to the variety of approaches and examples of designing and conducting educational design research – this is the main aim of this book. By presenting a varied collection of 51 examples of successful EDR projects, this book should be seen as an extension to our 2009 book. This means that the complete book now comprises of two volumes, viz Part A being a revision of our 2009 book, and Part B – this book – the collection of a rich variety of examples of successful EDR.

Part A (Plomp & Nieveen, 2013) presents an introduction to educational design research (Chapter 1 by Plomp), as well as a chapter that discusses how formative evaluation in educational design research can be designed and conducted (Chapter 6 by Nieveen & Folmer). Other chapters discuss design research from various angles: the curriculum perspective, the learning design perspective, a chapter with an example from the domain of instructional technology, and also a chapter discussing when design research is an appropriate research design. Part B – this book – presents a collection of 51 cases of successful design research coming from many domains in the field of education (such as curriculum, learning and instruction, subject related pedagogy, instructional technology, ICT in education) and reflecting various purposes of design research. The cases cover all education levels, including a few cases on workplace learning), and report research conducted in a wide variety of countries.

<sup>1</sup> In this chapter we use research approach and research design synonymously.

This collection of cases supplements other books and articles introducing educational design research (– sometimes using another names for this research approach). Examples are the books of Kelly, Lesh and Baek (2008), McKenney and Reeves (2012), Reinking and Bradley (2008), Richey and Klein (2007), and Van den Akker, Gravemeijer, McKenney and Nieveen (2006). Of the many articles, we mention here Ann Brown's (1992) article introducing the idea of design experiments, Barab and Squire (2004) on design-based research, Cobb, Confrey, DiSessa, Lehrer and Schauble (2003) on design experiments, Eilks and Ralle (2002) about participatory action research and Fishman, Penuel, Allen and Cheng (in press) about design based implementation research. Moreover, over the years, a number of special issues of journals have been published about design(-based) research and EDR projects have been reported in many articles. Please, refer to part A of this book (chapter 7) for details of these and other publications on educational design research.

The next section presents a brief introduction to educational design research including a number of characteristics of this research approach or research design, with a reference to Part A where these are discussed in greater detail. This overview will be followed by an account of how the collection of cases presented in this book was assembled. We describe how we aimed for a variety of cases, what guidelines were given to authors, and how the review process was organized. Next, we will provide an overview of the collection, describing – from a helicopter view – what readers can expect when browsing through the collection and reading the cases. In the final section the structure of the book of cases will be presented, as well as some recommendations for how this collection can be used.

## **2. Brief introduction to educational design research**

Educational design research is a research approach (or research design) appropriate to address complex problems in educational practice for which no how-to-do guidelines are available , or to develop or validate theories (e.g.) about learning processes, learning environments and the like. This variation in purpose is reflected in the definition of design research discussed in Part A, Chapter 1, where we introduce the distinction between *development studies* and *validation studies* respectively – see also Nieveen, McKenney and Van den Akker (2006).

In the remainder of this section we will briefly summarize some aspects of educational design research: its definition and twofold yield, the type of research question and its cyclical nature, its scientific character, and generalizability in design research. These issues are discussed more extensively in part A of this book.

### **Definition of design research and its twofold yield**

As stated above, two possible purposes of design research can be identified. Dependent on the purpose of the design research, we distinguish between *development studies* and *validation studies* respectively.

In the case of *development studies*, the purpose of educational design research is to develop research-based solutions for complex problems in educational practice. This type of design research is defined as *the systematic study of designing, developing and evaluating educational interventions (such as programs, teaching-learning strategies and materials, products and systems) as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them.*

On the other hand, in *validation studies* the purpose of design research is the development or validation of a theory, and this type design research is defined as *the systematic study of designing, developing and evaluating educational interventions (i.e. learning processes, learning environments and the like) with the purpose to develop or validate such theories.*

Design research always has a twofold yield, namely, on the one hand research-based interventions, and on the other hand knowledge about these interventions (in development studies), or theories based on them (in validation studies). The twofold yield of design research is one of its key characteristics and is also found in definitions and descriptions of other authors who sometimes use another name for this type of research. But all authors aim to what Barab and Squire (2004, p. 2) describe as “new theories, artefacts, and practices that account for and potentially impact learning and teaching in naturalistic setting”. We use ‘intervention’ to capture the rich variety of research-based curricula, artefacts and teaching-learning practices.

A further differentiation of design research is conceivable. For example, one can imagine that the *dissemination and implementation* of a particular program is supported by design research – the resulting intervention is the successfully disseminated and implemented program (e.g. at the level of a school system), whilst the systematic reflection and documentation of the process may lead to a set of procedures and conditions for successful dissemination and implementation (the design principles) for such programs.

The differentiation between these types of design research, serves mainly conceptual purposes. In practice, design researchers may combine orientations in their research. For example, starting from a complex and persistent problem in education practice, the research group may decide to apply design principles (‘local theories’) that resulted from other studies. In doing so they are not only developing an intervention, but at the same time exploring the validity of design principles (theory) developed in another context for their own problem context.

### **Research question and design research phases**

Researchers may have various reasons to embark on design research efforts, but all studies combine two orientations, viz design and research. This is nicely characterized by Kelly, Lesh and Baek (2008, p.xiii) who characterize design research as an emerging methodology in education “whose goal is to synergize the study of learning and teaching at *the intersection of design processes and research methods* (Italics by us). Design processes are systematic, creative, dynamic, generative, and directed at solutions to real problems; whereas, research methods are systematized, rule-governed, tied to standards of evidence and warrant, and directed at establishing principles, theories, and laws.”

Design researchers are striving to design an optimal intervention and to identify valid design principles (or a local theory) for these interventions in a certain context. Typical research questions in a development study type of design research can be phrased as: “*What are the characteristics of a good quality <intervention X> for the purpose/outcome Y (Y<sub>1</sub>, Y<sub>2</sub>, ..., Y<sub>n</sub>) in context Z?*” An example of such a research question can be found in Chapter 40 of this book where Dowse and Howie phrase as their research question “What are the characteristics of an intervention for promoting academic research writing which will best support master’s students in education in the proposal stage of their research?”. Please, refer to the chapters in this book (for instance chapters 30 and 51) for other examples. Based on prior work, Nieveen (1999; see also 2009 and part A – Chapter 6) proposes criteria for good quality interventions, implying that a complete and final version of an intervention should be:



- *Relevant*: There is a need for the intervention and its design is based on state-of the art (scientific) knowledge – also called *content validity*;
- *Consistent*: The intervention is 'logically' designed – also called *construct validity*;
- *Practical*: The intervention is usable in the setting for which it has been designed;
- *Effective*: Using the product results in desired outcomes.

In *development* studies, we usually distinguish a number of phases in which design and research activities are intertwined:

- *preliminary research*: needs and context analysis, review of literature, development of a conceptual or theoretical framework for the study;
- *development or prototyping phase*: phase consisting of iterations of analysis, design and formative evaluation, each being a micro-cycle of research with formative evaluation as the most important research activity aimed at improving and refining the intervention;
- *assessment phase*: summative evaluation to conclude whether the solution or intervention meets the pre-determined specifications.

Similar research phases are found in validation studies. For example, Cobb et al. (2003) distinguish between the phases of *preparing for a design experiment*, *conducting a design experiment* and *conducting a retrospective analysis*.

Throughout all these activities the researcher or research group will do *systematic reflection and documentation* to produce the theories or design principles as the scientific yield from the design research. Some authors include the *implementation* of the intervention, i.e. putting the intervention into practice, also as a phase in design research - for example McKenney and Reeves (2012) and Penuel, Fishman, Cheng and Sabelli (2011) who are speaking of design-based implementation research. We acknowledge that the dissemination and implementation of a particular program (intervention) can be a real challenge and suggest that such processes of upscaling can be supported by design research as well. However, we think that it is important to distinguish the research-based development of an intervention ('proof of existence') from the processes of dissemination and upscaling.

The iterative nature of the development or prototyping phase is needed for the 'successive approximation of the practical products' (or 'interventions') and the 'successive approximation of theory' (or 'design principles') – terminology taken from Wademan (2005). Each iteration or cycle is a micro-cycle of research, i.e. a step in the process of conducting the design research. Each iteration will have its own research or evaluation questions and consequently its own research design and will include systematic reflection on the theoretical aspects or design principles in relationship to the status of the intervention, resulting in either the decision that the intervention is not yet optimal so that another iteration is needed, or in the conclusion that the intervention is 'good enough', i.e. meeting the expectations of the research group for that iteration. In the first case a re-design, refinement or revision of the intervention is needed, which goes hand-in-hand with the refinement of the intervention theory or design theory. These features and characteristics of design research are nicely captured by Wademan (2005) in what he calls the generic design research model (see also Part A, Chapter 1).

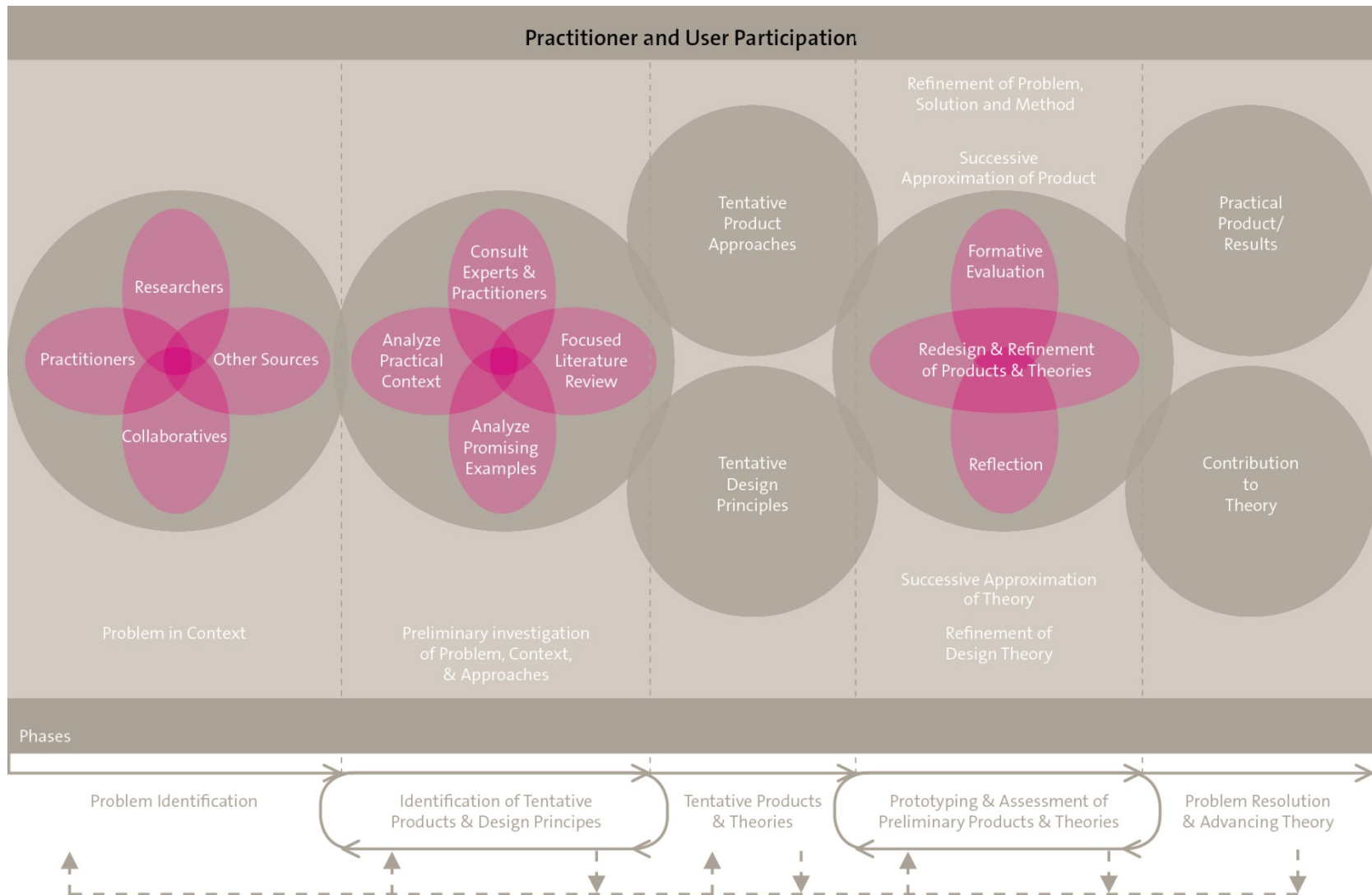


Figure 1: Generic design research model (Wademan, 2005)

### **Scientific nature of design research**

Like other researchers, educational design researchers need to meet criteria of good research and therefore to apply the guiding principles for scientific research (Shavelson & Towne, 2002), viz:

- Pose significant questions that can be investigated;
- Link research to relevant theory;
- Use methods that permit direct investigation of the question;
- Provide a coherent and explicit chain of reasoning;
- Replicate and generalize across studies;
- Disclose research to encourage professional scrutiny and critique.

For each cycle the researcher (or research team) applies the methodological 'rules' for doing research, i.e. for identifying the target audience and sampling, for instrument development and apply triangulation to obtain good quality data. Given the layers of formative evaluation in design research, in the later stages of development the evaluation design needs to be more rigorous than in earlier stages.

Design research is conducted in close collaboration with educational practice. Educational practitioners are actively involved, often as members of the research team. This leads to a number of challenges that are typical for this type of research, such as the risk that possible multiple roles of the researcher may jeopardize the quality of the research and the fact that real-world settings may imply real-world complications. Several measures can be taken to compensate for potential conflicts of interest - with reference to the guiding principles for scientific research (mentioned above) one may think of:

- make research open to professional scrutiny and critique by people outside the project;
- have a good quality research design with a strong chain of reasoning, triangulation, empirical testing and a systematic documentation and reflection of the design, development, evaluation and implementation process and their results;
- pay attention for validity and reliability of instruments and data.

See for a more detailed discussion Plomp in part A of this book, Chapter 1.

### **Generalizability in design research**

In design research, like in case studies and experimental studies, the findings cannot be generalized automatically to a larger universe (there is no statistical generalization from a small sample to a population, as in the case of survey research). Building on Yin (2003) we argue that yet design researchers have to strive to generalize their findings to a broader theory (Plomp, 2009, 2013). Design principles or local (instruction) theories must be tested through replications of the findings in a second, third or in more cases in various contexts with the purpose that the same results should occur. Once such replications have been made, the results might be accepted for a much larger number of similar contexts, even though further replications have not been performed. This replication logic is the same that underlies the use of experiments and allows experimental scientists to generalize from one experiment to another. Yin (2003) calls this *analytical generalizability*.

## **3. The act of assembling the collection**

The general purpose of this book (providing a rich number of examples to give students and novice researchers examples and insights in how to design and conduct an EDR-project) implied that we strived for cases reflecting a good variation of design research studies. In this section we describe the process of preparing the collection of cases. First we summarize some important dimensions that we wanted to be well-represented in the book. Then the guidelines

for the authors will be summarized, which will be followed by a description of the thorough review process.

### **Variety of cases**

As researchers may have various reasons to embark on design research, we aimed for a variation in *focus* of the cases of design research, such as the focus on the development of innovative interventions, on the development and validation of (instructional, pedagogical or learning) theories and on the dissemination and implementation of interventions. Moreover, the collection of cases was to cover studies in all educational sectors, was to represent a wide variety of domains in the field of education sciences (such as curriculum, learning and instruction, subject-related teaching methods, school organization, instructional technology, ICT in education) and was to provide studies on a variety of types of interventions (curriculum (units), authentic tasks, assessment tasks, monitoring systems). Based on our network of researchers and using the 'snowball approach' (inviting experts in the field of EDR to nominate good examples of design research), we found researchers from more than 23 countries from all over the world willing to contribute to this book, eventually leading to a collection of 51 cases. In section 4, we will describe the collection of cases on a number of dimensions.

### **Author guidelines**

An important starting point was that authors should have as much freedom as possible in describing their cases. However, as the cases are meant as examples from which graduate students and novice researchers should be able to learn how to design and conduct a project utilizing EDR as the research approach, we proposed that each chapter should address a number of topics that are not only characteristic for good research, but are also exemplary for a good case of educational design research. We considered it important that a reader will get a good understanding of the research design which implied that a clear description of the '*chain of reasoning*' for the research was necessary. We therefore suggested the authors to address in their chapter at least the following six issues or topics (each containing more detailed guidelines):

1. Introduction to the problem.
2. Development of conceptual framework/conceptualization of study.
3. Research design.
4. If applicable for the project: Assessment phase.
5. Yield of the project.
6. Reflection, lessons learned.

As indicated, we did not want to impose a 'straitjacket' of guidelines, as each researcher did conduct the research within the context and culture of their research group. But by requesting to address the issues mentioned, we hoped that graduate students and novice researchers will be able to understand how a particular design research project has been designed and conducted. Finally, as we can imagine that readers would be interested in further details of the study, we asked the authors to include, at the end of their chapter, a few key sources for the research they reported in the chapter.

### **Reviewing process**

As we strove for optimal quality of the contributions, a thorough reviewing process was set up comprising of three layers. First of all, each manuscript was reviewed by the two volume editors. For this first review, we used the author guidelines as a check list, but also checked whether the overall 'chain of reasoning' for research had been applied in a way that the target reader would

be able to understand how a particular piece of research was designed and conducted. In a few cases, we considered a further revision desirable.

In the second round, each (revised) manuscript has been blindly reviewed by two peers of which at least one was not from the same country as the author(s). We also tried to find for each manuscript peer reviewers of whom at least one had another background than the author(s). Two examples to illustrate this principle: a chapter focusing on mathematics education has been peer reviewed by another math educator and curriculum specialist, whereas a chapter on an ICT application in teacher education has been peer reviewed by an instructional technologist and a language educator. The peer reviewers were given as the 'key criterion' whether the chapter was written in a way that we may expect that graduate students and novice researchers (many not being native English speakers) can learn how the particular EDR project has been designed and conducted. Specific aspects for their review were:

- Does the title clearly describe the case reported?
- Does the abstract clearly summarize the case reported?
- Does the manuscript provide a sufficient account of the 'chain of reasoning' (or the various steps) for the research presented, i.e. is the research design sufficiently clear?
- Do the findings and conclusions follow up on these? Has been discussed at the end of the manuscript to what extent the main question is answered?
- Is the manuscript written in a style that is expected to be clear and understandable for graduate students and novice researchers who are not native English speakers.

Authors revised their manuscript on the basis of the peer reviews and were asked to submit also a memo indicating how they had dealt with the peer feedback. In a few cases the peer reviews resulted in a major revision of a chapter, after which the volume editors did another close review.

Finally, as a third layer, for a period of two months chapters were placed on a website only accessible for the authors of case chapters allowing them to read the other chapters and to do – if they would like so – an 'open peer review' and to provide feedback to colleagues and/or to include in their own chapters a reference to relevant other chapters. This has resulted in a few cases to some alterations in the chapters.

The entire reviewing process resulted in a collection of cases of successful design research, that may vary in focus and approach to design research and in the details of reporting the research, but that in our view also resulted in a set of case chapters that meets the purpose of the book.

#### **4. Describing the collection of cases**

The collection of cases represents a wide variety educational design research studies. To provide those who want to explore the collection of EDR cases with a tool to select a subset of cases appropriate for her/his use, we have asked the authors to describe their case on a number of dimensions of which we think that these will be relevant for exploring the collection of EDR cases. The description dimensions were deducted from our perspective on the purpose of the book, but we also included dimensions developed by Anderson and Shattuck (2012). See the Appendix for the description of the dimensions sent to the authors. The case descriptions formed the input for the case selection tool (available at the website of this book <http://international.slo.nl/edr>). In the remainder of this section we provide – with an helicopter view – an impression of the collection of cases.

### Countries

Figure 2 shows that successful cases on educational design research can be found all around the world. In total, 23 countries formed the context of the various design research studies (in some instances these are different from the countries where authors originate from). The USA and the Netherlands are best represented.

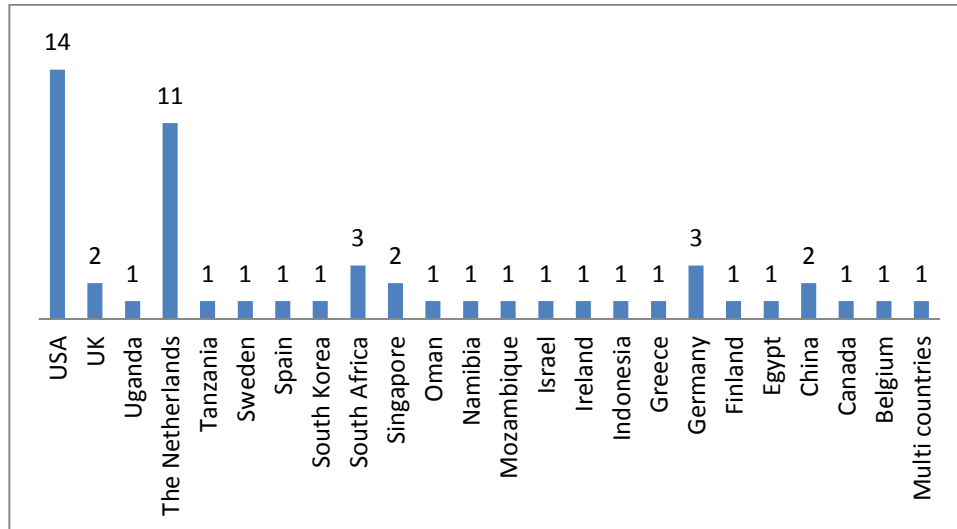


Figure 2: Countries that were context of the design research studies (N=51)

### Educational sectors

Figure 3 illustrates that the cases are well spread over the various educational sectors. Some authors stated that their study was carried out in two or more sectors. We asked these authors to select one educational sector as being the main sector of their studies. All authors were able to do so.

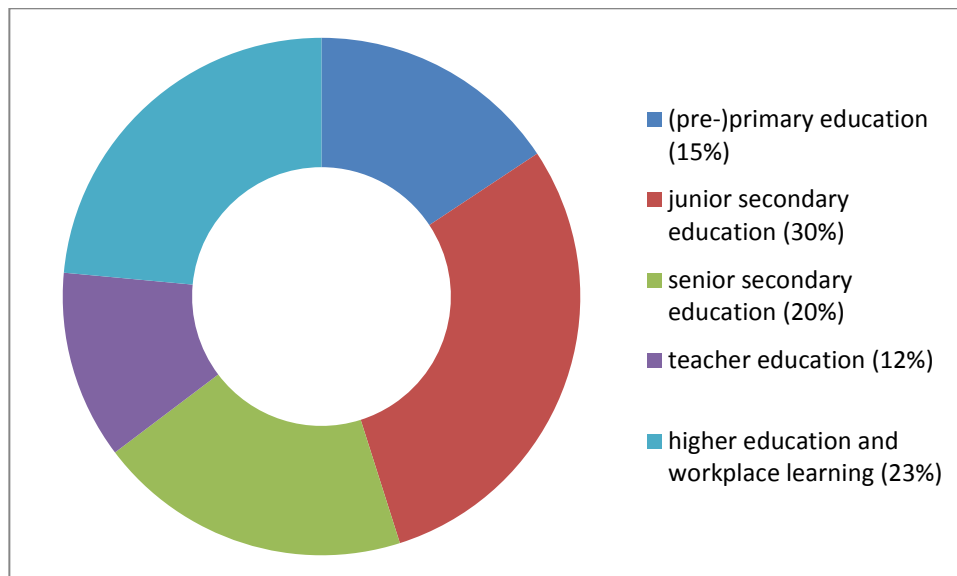


Figure 3: Main educational sectors that were context of the design research studies (N=51)

### Educational domains

Figure 4 depicts the educational domains represented in the cases. Understandably, authors mentioned various combinations here, for example ICT in education and subject-related pedagogy. Most studies in the collection (n=34) are linked to one of the domains of subject-related pedagogy, followed by the domain of learning and instruction (29 studies). Meaningful numbers are also in the domains of curriculum (16) and ICT in education (11) and the related domain of instructional technology domain (7). It is noteworthy that only three studies have been conducted on school organization and management. This might be due to the fact that the design research approach originated in the other domains. However, these cases may become illustrative examples and a basis for further developments in this area. Finally, six cases are related to other domains, such as teacher education and adult education.

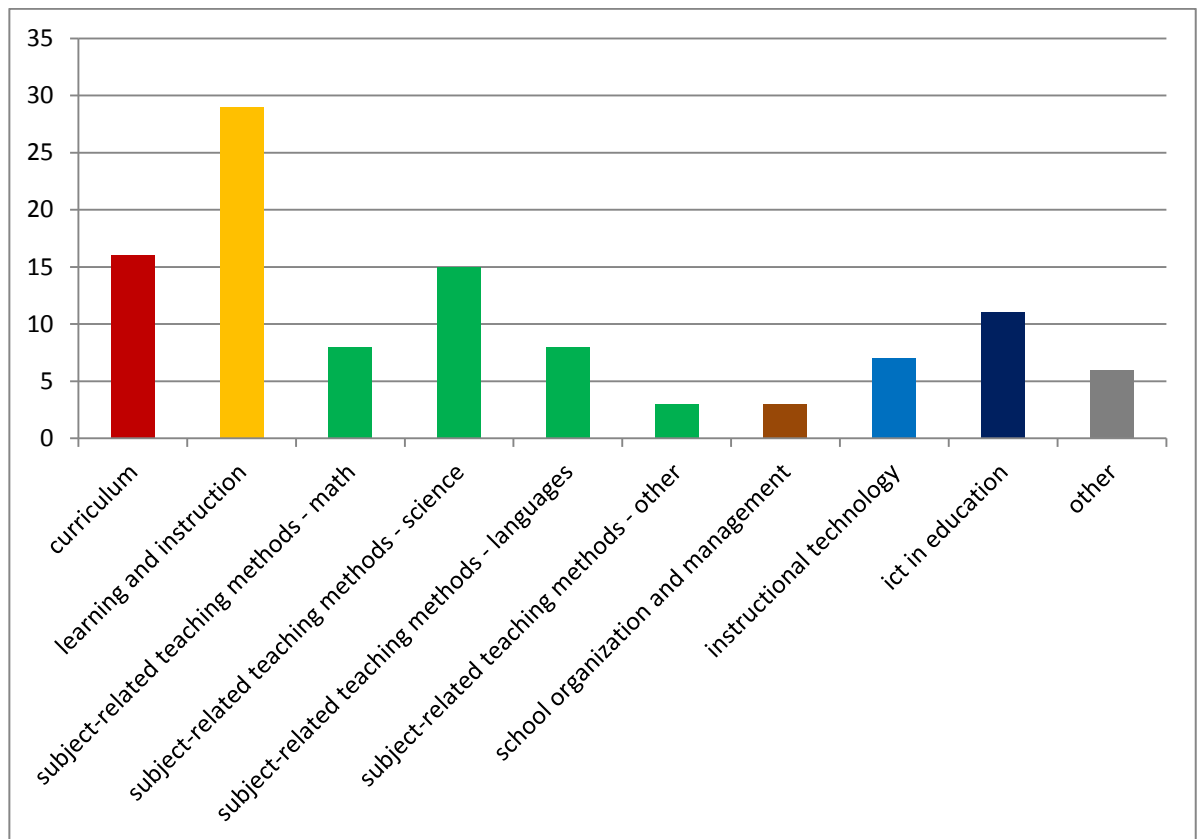


Figure 4: Educational domains represented in the design research studies (N=51)

### Main aim of the design research

Earlier on we introduced three main types of design research studies: development studies (aimed at solving educational problems for which no how-to-do solutions are available), validation studies (aimed at developing and/or validating theories) and implementation studies (aimed at successfully disseminating and implementing educational interventions). In validation studies a differentiation can be made between studies aimed at developing local theories (e.g. local instruction theories) and studies aimed at validating design principles that evolved from other design research studies. Figure 5 displays that more than 2/3 of the cases in the collection can be typified as being development studies; almost 1/3 are validation studies (14 with focus on theory development and 3 on theory validation) and one study can be labeled as an implementation study.

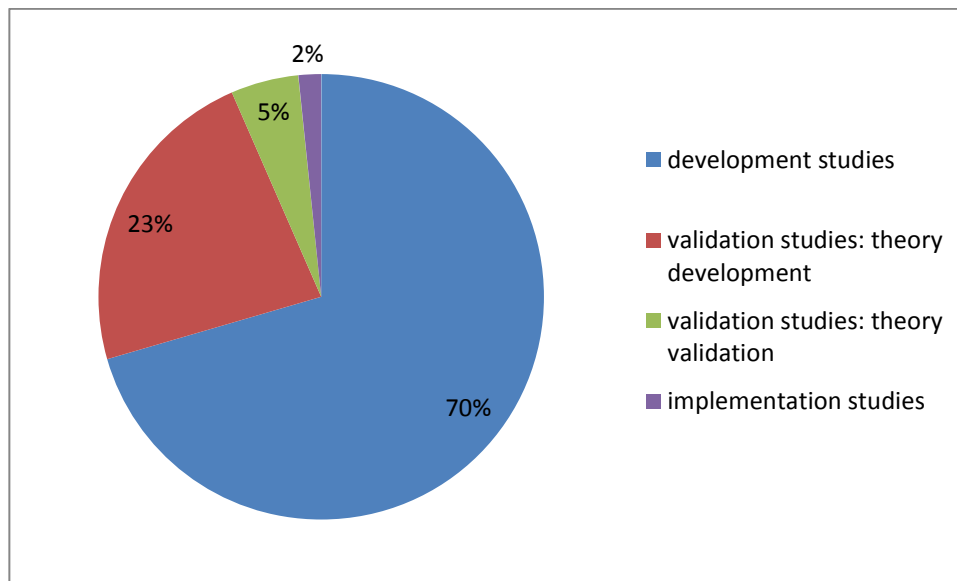


Figure 5: Main aims of the design research studies (N=51)



### Type of intervention

Finally, Figure 6 depicts the type of interventions that resulted from the various design research studies in the collection. Again, many authors mentioned that the intervention of their studies could not be typified with just one category. When looking at the interventions described in the collection, curriculum units (courses and modules) can be found most (n=34), followed by educational program/curriculum (n=12) and learning tasks (n=9), monitoring systems (n=4), assessment tasks (n=2) and other (n=4).

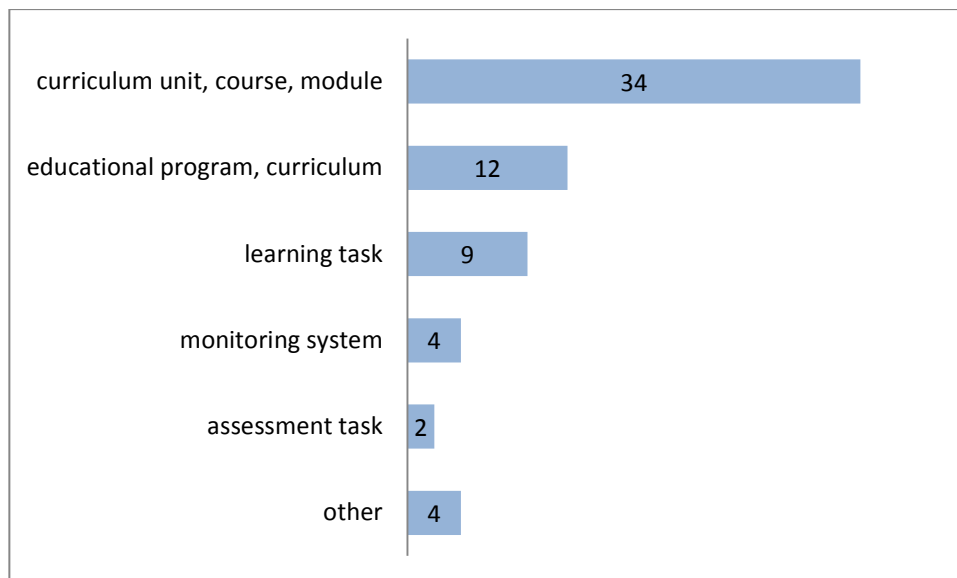


Figure 6: Types of interventions developed in design research studies (N=51)

Note: the total in the figure is higher than 51, the number of cases, because some studies aimed for more than one type of intervention.

## 5. Using the collection of cases

As stated, the purpose of this book is to provide graduate students and novice researchers – many not being native English speakers – with a variety of examples of design research as an aid in learning how to design and conduct their own research. Of course, each user will decide on how to use this ‘supra-book’, i.e. which cases of design research will be of interest and selected for studying, reviewing and analysis.

However, by emphasizing in this chapter the importance of the chain of reasoning for research (see e.g. Krathwohl, 1998) and by presenting the guidelines for authors, as well as for peer reviewers we wanted to provide the readers and users of this book with some helpful angles for analyzing the cases.

The case selection tool available at the website this book (<http://international.slo.nl/edr>) gives users the opportunity to select specific cases. By indicating (and combining) their areas of interest (such as main aim of the design research study, education sector, educational focus, type of intervention, underlying vision, domains in education sciences and country), users can select, download and read or use a subset of cases that look most appealing to them.

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## Appendix Dimensions of the description matrix

<p><b>1. Main focus/aim of the design research</b></p> <ul style="list-style-type: none"> <li>a. Development of innovative intervention (i.e. for which no clear guidelines and examples are available)</li> <li>b. Development of a new (instructional, didactical or learning) theory</li> <li>c. Validation of a (instructional, didactical or learning) theory</li> <li>d. Dissemination or upscaling of interventions</li> <li>e. Other, viz ...</li> </ul>
<p><b>2. Education sector</b></p> <ul style="list-style-type: none"> <li>a. Pre-school (0-4 year olds)</li> <li>b. Kindergarten (4, 5 year olds)</li> <li>c. Primary (6-11 year olds)</li> <li>d. Junior secondary (12-15 year olds)</li> <li>e. Upper secondary (16,17 year olds)</li> <li>f. Upper secondary (vocational)</li> <li>g. Teacher education (indicate for which subject and sector)</li> <li>h. Higher education general (indicate university/college level; faculty discipline)</li> <li>i. Corporate learning</li> <li>j. Non-formal (or informal) education and training (e.g. workplace learning)</li> <li>k. Other, viz ...</li> </ul>
<p><b>3. Educational focus</b></p> <ul style="list-style-type: none"> <li>a. Curriculum/school-related disciplinary focus of the research: <ul style="list-style-type: none"> <li>1. Can be <i>school subjects</i>: science, math, literacy, English language, mother tongue, etc.; but also: vocational subjects</li> <li>2. Can be <i>generic topics</i> such as cross-curricular skills (e.g. 21st century skills), use of ICT/computers/social media, library skills</li> <li>3. Combination of the above, viz ...</li> <li>4. Other, viz ...</li> </ul> </li> <li>b. Other school/institution-related focus, e.g. <ul style="list-style-type: none"> <li>1. Teaching-learning methods</li> <li>2. Curriculum planning</li> <li>3. ICT in education</li> <li>4. School management or leadership</li> <li>5. Monitoring quality of education</li> <li>6. Professional development of teachers</li> <li>7. Other, viz ...</li> </ul> </li> <li>c. Corporate learning related focus: <ul style="list-style-type: none"> <li>• ...</li> </ul> </li> <li>d. Other, viz ...</li> </ul>
<p><b>4. Type of intervention</b> (that was developed as part of the DR study)</p> <ul style="list-style-type: none"> <li>a. Education program, curriculum</li> <li>b. Curriculum unit, course, module</li> <li>c. Authentic tasks</li> <li>d. Assessment tasks</li> <li>e. Monitoring system</li> <li>f. Other, viz ...</li> </ul>

<p><b>5. Underlying vision on Teaching/Learning</b> (as utilized/applied in intervention)</p> <ul style="list-style-type: none"> <li>a. Problem-based learning</li> <li>b. Competence-based education</li> <li>c. Constructivistic approach</li> <li>d. Distance learning/e-learning</li> <li>e. Other, viz ...</li> </ul> <p>[NB: Combinations are possible, such as problem-based + eLearning; or constructivistic approach + problem-based education; This dimension may not be applicable to certain cases of EDR]</p>
<p><b>6. Domain(s) in education sciences</b></p> <ul style="list-style-type: none"> <li>a. Curriculum</li> <li>b. Learning and instruction</li> <li>c. Subject-related pedagogy/teaching methods, such <ul style="list-style-type: none"> <li>1. math education,</li> <li>2. science education</li> <li>3. language education</li> <li>4. other</li> </ul> </li> <li>d. School organization/management</li> <li>e. Instructional technology</li> <li>f. ICT in education</li> <li>g. Other, viz ...</li> </ul> <p>[NB: combinations are possible, e.g. ICT in education and subject-related pedagogy]</p>
<p><b>7. Country (or educational system) that was context of the research</b></p> <p>[NB: could be different from country where authors live]</p>
<p><b>8. Please provide a brief 'portrait' of your chapter</b> (50-100 words)</p> <p><i>(only information (in addition to previous points) that you consider essential for a reader when considering selecting this case for further use)</i></p>



## A Formative Experiment to Enhance Teacher-Child Interactions in a Preschool Classroom

Barbara Bradley

SLO • Netherlands institute for curriculum development

Bradley, B. (2013). A formative experiment to enhance teacher-child interactions in a preschool. In T. Plomp, & N. Nieveen (Eds.), *Educational design research – Part B: Illustrative cases* (pp. 1-21). Enschede, the Netherlands: SLO.

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Credits



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# 1. A formative experiment to enhance teacher-child interactions in a preschool classroom

Barbara Bradley

## Abstract

*This case presents a formative experiment investigating how two strategies aimed at increasing the quality and quantity of language interactions could be integrated into a preschool classroom. Strategies for enriching language interactions were introduced during book sharing, semi-structured group activities, and mealtimes. Mixed methods revealed factors that enhanced, inhibited, or sometimes prevented the integration of enriching language interactions during the school day and accordingly what adaptations might be warranted. This chapter also presents the literature and design principles that informed the study and the framework for conceptualizing and conducting a formative experiment. Further, it discusses lesson learned, and it provides issues for researchers to consider before conducting a formative experiment.*

## 1. Introduction to the problem

Developing children's oral language is an important goal of preschool instruction, because it is foundational to literacy development and subsequent reading achievement (NELP, 2008; NICHD, 2005). Yet, many children have impoverished opportunities to develop foundational oral language skills that will help them to be successful in school (Hart & Risley, 1995). Specifically, children who enter school with poor oral language skills often experience difficulties in learning to read (NICHD 2005; Torgesen, 2002). Thus, enhancing children's oral language skills, particularly children from low-socioeconomic homes, has been argued to be a priority in preschool classrooms (Neuman, Newman, & Dwyer, 2011).

Preschool teachers are in a good position to enhance children's oral language skills and to mitigate deficits. However, they may resist or have difficulty implementing potentially useful interventions, particularly when those interventions conflict, for example, with established programs with less emphasis on language development, with teachers' beliefs about the needs of young children, and/or with classroom routines for managing instruction (Schwartz, Carta, & Grant, 1996; Wells & Wells, 2001). Thus, this formative experiment investigated an intervention aimed at enhancing oral language development by integrating more productive language interactions between preschool teachers and children throughout the school day (see Bradley & Reinking, 2011a for more information about this study). Specifically, the aim was to determine what factors enhanced or inhibited teachers' ability to implement the intervention effectively and how the strategies and activities might be adapted to facilitate successful integration into the teachers' instructional routines (Walker, 2006). The methodological approach was a formative experiment, which is within the domain of design research, and it is an approach that literacy researchers have used (e.g., Baumann, Ware, & Edwards, 2007; Ivey & Broadus, 2007; Reinking & Watkins, 2000). The origin of the term "formative experiment" can be traced to Newman's (1990) study aimed at using computer-based activities to transform the teaching and learning of science concepts.

A formative experiment, like design research, tests and refines an intervention within an authentic educational setting. Further, like design research (Bradley & Reinking, 2011c; Cobb,



Confrey, DiSessa, Lehrer, & Schauble, 2003) it is (a) grounded in theory, (b) goal-oriented to improve education and learning, (c) intervention centered in an authentic educational settings, (d) involves iterative cycles of implementation and modifications, (e) transforms the educational settings, (f) methodologically inclusive and flexible, and (g) pragmatic. However, literacy researchers who conduct a formative experiment use a framework of guiding questions (Reinking & Bradley, 2008), which will be presented later in this section. These questions address and go beyond testing and refining an intervention and ask the researcher to consider how the intervention influences other aspect of the educational setting, and to identify unanticipated outcomes. That is, while both design research and formative experiments focus on developing an effective intervention or product that is feasible for teachers to implement, a formative experiment considers how an intervention can have positive and/or negative influences on the classroom environment that goes beyond the focus on the intervention. We believe that a formative experiment is well suited for conducting research in preschool classrooms because the instructional intervention is the object of study and it is aimed at changing teachers' practices and potentially transforming the classroom environment (Bradley & Reinking, 2011a, 2011b). A formative experiment also helps teachers and researchers to explore and confront their beliefs through a close collaboration. Thus, a formative experiment often facilitates the professional development of teachers, as well as enlightens researchers whose theories of instruction may be tested and refined when applied to the realities of classroom practice.

The framework for conceptualizing, conducting, and reporting a formative experiment (Reinking & Bradley, 2008) is comprised of the following six questions:

1. What is the pedagogical goal of the experiment, and what theory establishes its value?
2. What is an instructional intervention that has potential to achieve the pedagogical goal?
3. What factors in the environment enhance or inhibit the intervention's effectiveness in achieving the goal?
4. How can the intervention and its implementation be modified during the experiment to achieve the goal more effectively?
5. Has the educational environment changed as a result of the intervention?
6. What unanticipated positive or negative effects does the intervention produce?

The pedagogical goal guiding the investigation was to enhance children's oral language skills by increasing the quantity and quality of teacher-child language interactions during several common preschool activities. The value of that goal is that children's oral language skills lay a foundation for developing literacy. The desired outcome was to understand and refine an intervention that gives teachers options for engaging children in enriching conversations during a variety of common activities that occurs in preschools in the United States (U.S.). That outcome is important because many preschool language interventions focus on vocabulary development as opposed to a broader range of language skills. That is, rather than emphasizing individual words, this intervention is meant to support children's abilities to communicate their ideas. Further, preschool language interventions often occur within the context of book sharing activities rather than throughout the school day (e.g., Wasik et al., 2006). Book sharing is when teachers read a book aloud to children, typically to the whole class. Also, teachers help children understand the content by asking questions and making comments, and by encouraging children to do the same. Thus, the research question was: How can the quantity and quality of teacher-child language interactions be increased during several common preschool activities to enhance children's oral language skills?

In this chapter I provide the empirical basis for the intervention, and I describe the intervention and design principles, as well as the phases of the formative experiment. I also discuss the factors enhancing and inhibiting the intervention's effectiveness, the outcome of the study, and

revisit the design principles. Finally, I reflect on lessons learned and provide suggestions for researchers using this approach.

## **2. Empirical basis for intervention**

In this section, I briefly present the literature related to children's language development, professional development, and teacher change that informed the study. Then I conclude by describing the language intervention design principles.

### **Children's Language Development**

The pedagogical goal of the investigation was to increase children's oral language skills by enhancing the quantity and quality of teachers' language interactions with children. The rationale for the intervention strategies is grounded in existing empirical findings. For example, seminal research by Hart and Risley (1995) identified several key factors that influence children's oral language development: (a) the quality of the language interaction between a child and a caregiver; (b) the quantity of language interaction between a child and a caregiver, and (c) the diversity of language content and structure a child hears. Further, Hart and Risley (1993) offered the following criteria for defining the quality of language interactions that enhance children's language development. Adults should listen carefully to a child's utterances, respond appropriately and in a positive manner to the specific content of a child's utterances, and encourage a child to elaborate on his or her talk. These factors and criteria guided the development of the strategies that comprised the intervention.

I also was guided by the literature about how teachers can respond orally to children to enhance language skills. According to Snow's seminal research (1983), a semantically contingent response expands on the content of a child's utterances, adds new information to the topic of discussion, requests a child to clarify utterances, and/or answers a child's questions. The frequency of semantically contingent responses is positively correlated with a child's oral language skills, whereas the frequency of semantically non-contingent responses is negatively correlated with a child's gains in language skills (Snow, 1983). Thus, I defined quality of language interaction by a teacher's use of semantically contingent responses to engage a child in extended conversations (6 or more exchanges) and increasing teachers' use of semantically contingent responses was one strategy that had the potential to enhance children's oral language skills.

Decontextualized demands (i.e., questions or comments requiring or inviting a response) move language interactions beyond an immediate context and engage a child in a more cognitively and linguistically challenging interaction. Decontextualized talk (Dickinson & Tabors, 2001) includes interactions that require reasoning skills and more complex language, such as defining words, predicting, and explaining. Research suggests that when children participate in decontextualized talk, they are more likely to develop advanced linguistic abilities (Dickinson & Tabors, 2000), and there is a positive correlation between the amount of decontextualized talk and early literacy abilities (Hindman, Wasik, & Erhart, 2012). Thus, increasing teachers' use of decontextualized demands was another strategy used in this study because it has potential to enhance children's oral language skills.

### **Professional development and teacher change**

The literature on professional development and teacher change was pertinent to the study and I was guided by three factors that may influence teachers' abilities to connect research and practice (Malouf & Schiller, 1995). First, teachers' attitudes and beliefs about teaching and research influence their ability to adopt new instructional practices. Second, contextual factors, such as the curriculum and instructional support, influence teachers' ability and desire to adopt

new instructional practices. Finally, teachers need time and opportunities to reflect on their knowledge and experiences in relation to the research findings. Reflection is a particularly important component of effective teaching (e.g., Schön, 1987) because teaching is a "complex, situation-specific, and dilemma-ridden" (Sparks-Langer & Colton, 1991, p. 37).

### **The intervention and design principles**

In a formative experiment the intervention may be a coherent, integrated cluster of instructional strategies or activities (Reinking & Bradley, 2008). Therefore, I attempted to increase teachers' use of two strategies, semantically contingent responses and decontextualized demands, during three activities in a preschool classroom: book sharing, semi-structured group activities, and mealtimes. These activities were identified, prior to meeting the teachers, because they are activities that regularly occur in preschool classrooms in the U.S. and they had the potential to support teacher-led and child-centered conversations (Dickinson & Tabors, 2001). Further, providing teachers with instructional guidance and support for engaging children in enriching language interactions throughout the school day has been advocated in the literature (Dickinson, McCabe, & Essex, 2006).

In sum, when developing an intervention to support the oral language development of children, the first design principle was to develop an intervention that encourages teachers to focus on language interactions throughout the preschool day. The second design principle was to ensure teachers had different strategies that they might apply based on the needs of the children. That is, I identified one strategy, semantically-contingent responses, that encouraged teachers to following a child's lead, and engage children in extended conversations, and a second strategy, decontextualized demands, in which teachers could direct children's thinking and use of language. The third design principle was to develop an intervention that included activities of varying levels of structure. For example, book sharing is a highly structured activity in which the teacher leads the discussion of the book read aloud, whereas mealtimes are relatively unstructured activities and children can choose the topic of conversation. Further, when implementing the intervention, I recognized that teachers would need time and opportunities to reflect on their attitudes and beliefs about the instructional practices, and that there might be instructional or contextual factors that limited their adoption of various elements of the intervention. Thus, the final design principle was to create opportunities to discuss the intervention and to allow time for teachers to reflect on their instructional practices.

## **3. The study**

In this section, I first describe the methods and procedures and then present the baseline data related to teacher-child language interactions during book sharing, semi-structured activities, and mealtimes. Next, I describe the iterations in relationship to these three activities. Lastly, I describe the retrospective analysis, which includes addresses changes in the classroom environment and unanticipated results of the intervention. See Table 1 at the end of this chapter for a summary of research activities.

### **Methods**

#### ***Participants***

Participants included a preschool teacher, a paraprofessional, and 20 pre-school children. Ms. Kephart (all names are pseudonyms), the teacher, held a Master's degree in education and had 20 years of teaching experience. Ms. Davis, the paraprofessional, held a high school degree and had worked with Ms. Kephart for 3 years. The class was composed of 10 boys and 10 girls between 4 and 5 years old. Six children were classified as African American, 9 as European American, 5 as Hispanic; and, 19 of the 20 children received free or reduced lunch. The class

was located in an elementary school in a rural community in the Southeastern U.S. The teacher and paraprofessional were recruited for several reasons. First, at the time the present study was conducted, several local school districts were participating in a large federally funded research project; however, the district that these teachers worked were not involved in that project. Further, they met that criteria that both the teacher and paraprofessional were interested in participating in the study and willing to be video taped. Further, and most importantly, they believed that language development was an important component of a preschool program and that they believed they could do more to support their students. While I believe that it is important that schools and/or teachers identify educational problems they would like to address; in some instances, such as this dissertation study, that is not always possible. That is, I was not in a position to develop long term relationships with local preschools, help them to identify a problem, and then provide support based on my area of expertise.

### ***Procedures***

After the teacher and paraprofessional (henceforth, I use “teachers” to when referring to both the teacher and parapro) agreed to participate, in Phase I, baseline data was collected for 7 weeks. I observed in the classroom and the school to gain a thorough understanding of the context, and I interacted informally with the teachers and children to build trust and to accustom them to my presence. I gathered data systematically through a semi-formal interview and informal discussions with the teachers, classroom observations and field notes, and videotaping of book sharing and semi-structured group activities. I also administered language assessments to the children. At the end of the baseline phase, I presented the intervention to Ms. Kephart and Ms. Davis by (a) explaining the importance of preschool in developing children’s oral language, (b) describing research related to children’s language experiences at home and in school, (c) presenting the potential benefits of semantically contingent responses and decontextualized demands and providing examples of each type of interaction, (d) explaining the pedagogical goal and intervention in relation to their current practices, and (e) discussing how their practices might be adapted or enhanced. In Phase II, which lasted for 16 weeks, Ms. Kephart and Ms. Davis implemented the language strategies, and I continued to collect and analyze data to identify factors that were enhancing or inhibiting their ability to implement the intervention. Specifically, I collected video data of book sharing and semi-structured group activities, and took observation notes during mealtimes and playtime. Then, data were analyzed to determine the frequency of and types of questions and comments made during teacher-child conversations. Video clips, transcripts, and tentative findings were shared with the teachers so that we could discuss factors that were enhancing or inhibiting talk and to determine what steps might be taken to minimize the inhibiting factor and to increase children’s talk. Phase II also consisted of two iterations. The first iteration occurred between November and December and then we reviewed the intervention before beginning the second iteration, which occurred between January and March. At the end of this development phase, I debriefed the teachers in a semi-structured interview and re-administered the language assessments to the children. During a final phase, a retrospective analysis was conducted. That is, all sources of data were reviewed to gain a deeper understanding of intervention and to inform responses to questions five and six in the framework guiding this formative experiment.

### **The Baseline Phase**

#### ***Book sharing***

Before implementing the intervention, baseline data were collected to better understand the language environment of the class and how the teachers’ instructional practices aligned with the intervention. Seminal research by Blank, Rose and Berlin (1978) with preschool teachers

suggests that approximately 30% of teachers' demands should be decontextualized to support children's language and cognitive development. Taylor, Pearson, Clark, and Walpole (1999), also found that highly effective elementary school teachers used approximately this proportion of decontextualized demands with their students. Therefore, I used this proportion as the criteria for effective use of decontextualized demands. During the baseline period, book sharing activities were video recorded and transcripts were search for decontextualized demands. Ms. Kephart demands were above the recommended 30% level, whereas Ms. Davis' demands were below the 30% level. Therefore, there was potential for Ms. Davis to modify her book sharing interactions with children. The transcripts were searched for extended interactions and coded for semantically contingent responses. Although both teachers did use semantically contingent responses, the number of such responses that led to extended conversations (defined as more than 6 exchanges) was limited. Finally, based on field notes and interviews, the teachers did not read to children in small groups, nor was it a planned activity. Therefore, reading to children in a small group, which was part of the intervention, would be a new instructional activity for these teachers.

### ***Semi-structured group activities***

During semi-structured group activities, children were expected to listen quietly while the teachers gave directions; otherwise, they were allowed to talk freely as they engaged in activities (e.g., making a collage, building with small blocks). Coded transcripts of these activities showed that the proportion of decontextualized demands in which the teachers engaged the children was in all instances below the recommended 30%. The transcripts also were searched for semantically contingent interactions, which revealed few child-centered extended interactions.

### ***Mealtimes***

During breakfast Ms. Davis remained in the cafeteria with children. A timer with an alarm was set for 10 minutes and children were expected to eat and not talk until the alarm sounded. Nonetheless, after the alarm, Ms. Davis continued to encourage children to eat and not talk. During lunchtime, both teachers ate lunch with the children in the cafeteria, and they would occasionally set the timer, again to regulate talking. In addition, to control the noise level in the cafeteria, there was a school-wide rule that when music was playing, talking was not allowed, which limited time for conversations. Analysis of field notes indicated that when the timer or music was not on, the teachers listened to the children's conversations and participated in talk when children directed a comment or question to them. However, as confirmed in an initial interview and informal discussions with both teachers, they were primarily concerned that the children ate nutritious meals. They did not identify mealtimes as an opportunity to interact verbally with children.

### ***Summary***

Baseline data demonstrated that whole-class book sharing, semi-structured group activities, and mealtimes were part of the teachers' classroom routines, as expected, yet language interactions during these times were teacher-directed, contextualized and provided limited opportunities for children to develop their oral language skills. Thus, there seemed to be much room to increase opportunities to engage children in enriching language interactions throughout the day.

## **Development phase: factors enhancing and inhibiting the intervention**

### ***Whole class book sharing***

During the first iteration, both teachers' proportion of decontextualized demands increased beyond levels observed during baseline. Although both teachers increased their use of decontextualized demands, I noticed that fewer demands were made after book sharing, compared to before and during the book-sharing event. Recognizing and sharing nuances of implementation is important because discussions after book reading has been shown to be particularly beneficial for children's language development (Dickinson & Smith, 1994). Despite sharing that finding with the teachers and developing open-ended statements to encourage discussion after book sharing, that pattern persisted during the second iteration. I speculate that greater attention to interactions before and during book sharing lengthened the activity and consequently raised concerns about children's attention, and these concerns led to decreased talk after book sharing. Nonetheless, alerting the teachers to the issue of decontextualized talk and discussing possibilities in the context of viewing videotapes of their teaching led to an increased use of decontextualized demands.

Although teachers engaged the children in more extended interactions during book sharing, these interactions were primarily teacher-led, rather than following a child's lead by using semantically contingent responses. After reviewing videotapes, it was apparent that teachers were concerned about maintaining children's attention and limited the number of turns that any one child had so that other children had opportunities to participate. Thus, a structured activity like book sharing may not easily lend itself to extended conversation with children.

### ***Small-group book sharing***

When I introduced the small-group book-sharing component of the intervention, Ms. Kephart resisted because she believed it conflicted with a hallmark of the High/Scope curriculum (Hohmann & Weikart, 2002), which includes many opportunities for children to choose activities. Further, Ms. Kephart was concerned that if both she and Ms. Davis were both reading to some children, they could not adequately supervise children who were not participating in the small group activity. Consequently, during the first iteration, the teachers did not implement small-group book sharing.

This illustrates how the curriculum and classroom management influence the extent to which aspect of and how an intervention is implemented. Although I believe that teaching in small groups is in the best interest of children, when conducting a formative experiment, it is necessary to see the intervention from a teacher's perspective and to understand what factors might prohibit implementing aspects of an intervention.

At start of the second iteration, Ms. Kephart indicated that she and Ms. Davis would consider small-group book sharing. Although she did not explain her reasons, it may have been based on her opportunity to reflect on the potential benefits of small-group instruction (Schön, 1987) during the first iteration. To accommodate her concerns about supervising the children, each teacher read to half the class, rather than to a small group of five to six children. Further, they would read to the children at the end of the school day when children typically participated in a whole-class activity. Nonetheless, book sharing was sporadic and did not seem to be fully integrated into the daily routine.

### ***Semi-structured group activities***

During the first iteration, the teachers continued to engage children in contextualized talk and although there were more extended interactions, they were typically teacher-led talk. To provide teachers with more opportunities to focus on individual children at their respective table, some

children were allowed to sit at a third table to work independently. The teachers attempted this modification on several occasions; however, it actually decreased teachers' interaction with children because they often were monitoring children at the third table.

Prior to the second iteration, the teachers and I discussed adopting a set of generic conversation starters that were observed occasionally during the first iteration and that supported decontextualized talk. Nonetheless, the data indicated that the teachers were not able to increase decontextualized demands to the 30% criteria. Teachers also had limited success increasing their use of semantically contingent talk to follow a child's lead. After reviewing the videotapes and transcripts, it became evident that decontextualized talk and child-centered extended interaction were difficult within the context of the activities. During art activities, for example, the teachers primarily helped children to share and manage the materials and during math activities (e.g., building with small blocks), the teachers primarily worked with children who struggled to learn basic concepts (e.g., counting).

### ***Meal times***

During the first iteration, Ms. Kephart joined the children for breakfast, and she and Ms. Davis discontinued the use of the timer to restrict talking. These changes immediately increased extended conversations between Ms. Kephart and the children, and particularly among the children. While Ms. Davis occasionally engaged children in extended conversations, she primarily allowed the children to talk among themselves and responded to questions and comments directed to her. Based on this documented increase in conversations, I suggested occasionally eating lunch in the classroom, like they did for their late afternoon snack, to avoid the music that cued no talking. However, that suggestion was rejected, because Ms. Kephart believed that it would be an inconvenience for the cafeteria staff and the custodian. Prior to the second iteration I revisited the issue of occasionally eating lunch in the classroom but once again the teacher indicated it would be an inconvenience for others.

Factors that emerged that influenced conversations during mealtimes were teachers concerns that children were eating nutritiously and a school-wide rule restricting talk to control noise. That is, teachers struggled to break well-established habits such as focusing on how much the children had eaten or telling them to stop talking when the noise rose, rather than viewing mealtimes as also a time to socialize. These factors illustrate how teachers' beliefs, practical issues, and policies can limit how an intervention is implemented. However, these limitations, revealed in this methodological approach, are necessary to acknowledge and to accept if they cannot be accommodated.

### **Retrospective analysis**

At the conclusion of the study, I conducted a retrospective analysis (Cobb, McClain, & Gravemeijer 2003) of the multiple data sources collected during the development phase to ensure a thorough and rigorous analysis to inform recommendations (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). Further, this analysis informed the responses to questions five and six in the framework guiding this formative experiment. Specifically, has the educational environment changed as a result of the intervention? and what unanticipated positive or negative effects does the intervention produce? I believe that these questions are particularly important when conducting classroom research, because researchers often do not consider how an intervention can influence instructional practices beyond what is planned. Responding to these questions can also lead to the development of pedagogical or design principles.

### ***Changes in the educational environment***

To determine if the educational environment had changed beyond the three identified intervention activities, data were collected and analyzed during morning and afternoon free play to determine if the teachers increased their language interactions with children. Free play was a time during which children chose their own activities with minimal restrictions.

Identifiable differences were not observed during morning free play because, in part, teachers used that time to take care of class business (e.g., take attendance, report lunch count, read notes from parents). Data from afternoon free play could not be used because during baseline children played outside, while during the intervention they play primarily inside due to colder weather. Nonetheless, Ms. Kephart indicated in a final interview that she developed an increased awareness of children's vocabulary knowledge, particularly during informal conversations. Ms. Davis also indicated that she believed she knew the children better and was more aware of their language abilities this year than in past years.

### ***Unanticipated effects of the intervention***

It is logical to assume that intervention strategies aimed at increasing teacher-child language interactions would deepen teachers' understanding of children's lives. However, I had not anticipated the distressing information that the teachers would learn about the children and the pervasive effect that knowledge would have on their teaching and the classroom environment. Specifically, the teachers learned that several children were witnessing family violence, and several children were suspected of being sexually abused. That information highlights dramatically in this study the many social-emotional needs of the children that may be revealed when teachers engage children in richer conversations. Further, it added stress to the teachers work and raised new responsibilities. Because these are sensitive issues with potentially dramatic consequences, I discussed them during our final interview. Ms. Kephart indicated that she might have learned about the children's troubled home life, but she believed that focusing on the children's conversation helped her to be more patient and it allowed children to share in greater detail their home-life situations with her.

In short, asking the teachers to focus on language interactions helped them to be more sensitive towards the children's lives inside and outside of school. Also, their more responsive approach may have allowed the children to develop a more secure relationship with them, which may have facilitated children's comfort and security in sharing their family situations with their teachers. Thus, one unanticipated positive outcome of interventions aimed at enhancing language interactions in a preschool classroom may be an increased awareness of children's personal lives.

## **4. Conclusions**

The results of the present study support previous research showing that preschool teachers can change their book sharing style (Wasik et al., 2006). It extends that research by suggesting that drawing attention to enriching language interaction along with viewing video clips, may lead to more decontextualized demands. Yet, the increased use of decontextualized demands occurred before and during book sharing and was followed by a decrease in such demands after book sharing. That finding is significant, because research indicates that rich discussions after book sharing are particularly important to language development (Dickinson & Smith, 1994). Thus, researchers and teachers should carefully consider the subtleties of how strategies are implemented. Further, the present study supports research showing that it may be difficult for preschool teachers to implement small-group book sharing (Whitehurst, Arnold, Epstein, Angell, Smith, & Fischel, 1994) and it adds a nuanced understanding of why implementation may be difficult for teachers.



The present study clearly demonstrates the extent to which context influences teacher-child interactions. For example, book sharing enabled teachers to increase their use of decontextualized demands and mealtimes allowed them to engage children in extended child-centered conversations. In contrast, semi-structured group activities, at least how it was implemented in this class, encouraged more contextualized talk. Further, the present study demonstrated that contextual factors that inhibit the implementation of an intervention might be, in some situations, beyond the control of a teacher to change.

Finally, the present study considered how the intervention might produce unanticipated effects in the environment. One unanticipated effect of intervention was that it increased the teachers' awareness of children's personal lives, which required the teachers shift their attention from teaching to seeking social services for the children and their families. This finding demonstrates the need for teachers and researchers to consider how an intervention may produce positive and negative influences, which formative experiments, unlike other approaches to research, reveal.

### **Professional development and classroom practice**

The present study provides several implications for professional development and classroom practice. First, teachers' beliefs clearly influence how they interact with children, how they structure activities, how they implement the curriculum, and so forth. Thus, it may be important to provide teachers with explicit opportunities to reflect on how their beliefs are instantiated and the consequences of those behaviours in relation to their educational practices.

The findings also suggest that the curriculum and the extent to which teachers are committed to it influence how they interact with children. Consequently to achieve a pedagogical goal, it may be necessary for teachers to implement approaches that might move them outside of their comfort zone, especially if that comfort zone is grounded in a set curriculum. Thus, teachers will need support to learn about and to implement a new approach, particularly if it is not easily merged into an established curricular framework.

### **Design principles revisited**

Supporting young children's oral language development is an important goal because it is foundational to literacy development and subsequent reading achievement. The intervention was designed to provide teachers with language strategies that they might implement during common preschool activities. The first design principle encouraging teachers to focus on language interactions throughout the preschool day was feasible, and based on interviews, teachers indicated that such interactions help them get to know their students better (see Bradley & Reinking, 2011a). The second design principle, encouraging teacher to use different strategies (i.e., decontextualized demands and semantically contingent responses) and the third design principle, including activities that varied in level of structure (e.g., highly structure to unstructured) were more interrelated than expected. That is, this study demonstrates how context guides or limits the types of language interactions. For example, structured activities (e.g., book sharing) may allow teachers to engage in more planned and decontextualized talk, while unstructured activities (e.g., mealtimes) may allow teachers to follow a child's lead and engage children in more extended. Although, the teachers in this study did not engage children in as many extended interaction as hoped due to a school-wide rule (i.e., no talking when music was played), there was potential for extended conversation. It may be possible that other unstructured times such as free play, when children choose their own activities, may lend itself better to conversations. Most enlightening were the semi-structured activities because both teachers tended to engage in few extended interaction with children and their talk was primarily directives (e.g., managing children's behaviors and task). While some activities can consist of

directives (Girolametto, Weitzman, Lieshout, & Duff, 2000), research also shows that they can provide opportunities for enriching talk (Girolametto, Hoaken, Weitzman, & van Lieshout, 2000). Ultimately, how teachers interact with children may depend on the activity and its objective, as well as the extent to which children need supervision. Further, research is needed to understand if and how such activities can be leveraged to support both the objective of the activity and oral language development.

The fourth and final design principle related to professional development, which is an important aspect of implementing an intervention, should provide teachers with time and opportunities to reflect on their beliefs and attitudes toward the intervention, its goal, and their instructional practices. While teachers did engage in self-reflection as evidenced by, for example, their comments when viewing video clips of their teaching and the teacher's decision to implement half-class book sharing during the second iteration (Bradley & Reinking, 2011a), it may be useful for several teachers in similar circumstances to discuss these issues related to an intervention. Further, to support teachers' self-reflection and to avoid a sense of being judged, researchers might focus on children's responses to help teachers to consider how their behaviors influence children's learning; sharing video recordings seem particularly helpful on this point.

## **5. Lessons learned**

The present investigation was my dissertation and, as new researcher, I believed that a formative experiment would help to reveal aspects of instructional interventions in preschool classrooms that are not as apparent through other approaches to classroom research. For example, conventional experiments require fidelity when implementing an intervention, regardless of contextual variables, including teachers' belief or professional decisions. For me, findings from this study demonstrated how strongly contextual variable influenced the process of integration and change. For example, the teachers easily increased their use of decontextualized demands during books sharing but struggled to consistently change patterns of talk during semi-structured activities. Thus, while teachers wanted to and did make changes to better support children's language development, changing instructional practices is a complex process that involves considering many issues such as tacit beliefs and behaviors, demands of class activities, and school policies and procedures. In short, this experience reminded me of the complexity of contextual variables in an educational environment and the demands placed on teachers. Further, I learned how deeply a teacher's style of language interaction and teaching is ingrained and personal. Thus, useful interventions or modifications that help to accomplish a pedagogical goal may be difficult to adopt, even when a teacher desires to do so (Rowe, 1998).

To support teachers and to avoid being evaluative, when discussing language interactions, I focused on how the children were responding rather than just what teachers were doing. While I had planned to show teachers the transcripts and videos, this study showed me how powerful videos are as part of professional development. Both teachers often noticed and commented on situations that helped them to better understand their practices, as well as students' behaviors, when watching the videos. Since conducting the present study, I have consistently collected and shared videos with teachers as part of research and professional development. Further, this technology is easier to use (e.g., videos can be downloaded almost instantly into a viewable format) and equipment is less expensive.

As a former preschool teacher, the teachers and I quickly developed a collaborative relationship and we could easily discuss issues related to the intervention, as well as other class issues. However, it wasn't until the final weeks of the study, when the welfare of some of the children came to the forefront that the true value of our collaboration became apparent to me. That is, at

that point in the study, our discussions focused as much on obtaining support for the children and their families as it did on the intervention. This highlights the realities and complexity of teaching and doing classroom research involving close collaboration between researchers and teachers. It also reminds me of Kaestle's (1993) argument that good education research is research that directly contributes to improving people's wellbeing, rather than forwarding a particular agenda. Further, it highlights the value of discussion among colleagues. As an unfunded project, the present study was small out of necessity. Thus, as possible, I believe that when conducting research, researchers should strive to build long-term relationships with schools and teachers, and research should create plenty of opportunities for teachers to talk with the colleagues. In sum, much can be learned when conducting research and often beyond the focus study.

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Table 1: Summary of research activities

Phase 1: Baseline – 7 weeks		
Data collected and analyzed	Findings	Intervention
<ul style="list-style-type: none"> <li>• Video recordings: Book sharing and semi-structured group activities</li> <li>• Classroom observation - all activities, including mealtimes</li> <li>• Child language assessments</li> <li>• Teacher Interviews</li> </ul>	<p><b>Whole-class book sharing</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Teacher meets expectation; parapro below expectations</li> <li>• <u>Semantically contingent talk</u>: Teacher and parapro below expectation</li> </ul> <p><b>Small-group book sharing</b></p> <ul style="list-style-type: none"> <li>• Did not implement</li> </ul> <p><b>Semi-structured group activity</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Teacher and parapro below expectations</li> <li>• <u>Semantically contingent talk</u>: Teacher and parapro below expectations</li> </ul> <p><b>Mealtimes</b></p> <ul style="list-style-type: none"> <li>• Teacher and parapro restricted or discouraged talk</li> </ul>	<ul style="list-style-type: none"> <li>• Presented decontextualized demands and semantically contingent talk strategies in relation to current practices</li> </ul>
Phase 2: Development - iteration 1: 7 weeks		
Data collected and analyzed	Findings	Modifications
<ul style="list-style-type: none"> <li>• Video recordings: Book sharing and semi-structured group activities</li> <li>• Classroom observation - all activities, including mealtimes</li> <li>• Informal interviews with teachers</li> </ul>	<p><b>Whole-class book sharing</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Teacher and parapro increased use of decontextualized talk before and during book sharing but less talk <i>after</i> book sharing</li> <li>• <u>Semantically contingent talk</u>: No change</li> </ul> <p><b>Small-group book sharing</b></p> <ul style="list-style-type: none"> <li>• Did not implement this activity</li> </ul> <p><b>Semi-structured group activity</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: No change</li> <li>• <u>Semantically contingent talk</u>: More extended talk but teacher-led</li> </ul> <p><b>Mealtimes</b></p> <ul style="list-style-type: none"> <li>• Discontinued use of timer to restrict talk; Teacher joined children for breakfast</li> <li>• Teacher increased talk with children; parapro less restrictive and responded to children's questions/comment</li> </ul>	<p><b>Whole-class book sharing</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Discussed and developed opened questions to support talk after book sharing</li> <li>• <u>Semantically contingent talk</u>: No modifications suggested</li> </ul> <p><b>Small-group book sharing</b></p> <ul style="list-style-type: none"> <li>• Concerns about adding another small group activity to the schedule</li> </ul> <p><b>Semi-structured group activity</b></p> <ul style="list-style-type: none"> <li>• Implemented small groups several times but too challenging to manage</li> </ul> <p><b>Mealtimes</b></p> <ul style="list-style-type: none"> <li>• Suggested eating some lunches in the classroom due to school rules limiting talk; teacher indicated it would be an inconvenience for support staff even though they ate snack in the classroom</li> </ul>

Table 1: Summary of research activities (continued)

Phase 2: Development - iteration 2: 8 weeks		
	<p><b>Whole-class book sharing</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Continued high levels of decontextualized talk before and after book share but still less <i>after</i> books sharing</li> <li>• <u>Semantically contingent talk</u>: No change</li> </ul> <p><b>Small-group book sharing</b></p> <ul style="list-style-type: none"> <li>• Implemented some small group book sharing and some half-class literacy activities</li> </ul> <p><b>Semi-structured group activity</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: No change</li> <li>• <u>Semantically contingent talk</u>: Continued extended talk but still teacher-led</li> </ul> <p><b>Meal times</b> Teacher continued talking with children; parapro continued to be less restrictive and respond to children</p>	<p><b>Whole-class book sharing</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Continued discussing opened questions to support talk after book sharing</li> <li>• <u>Semantically contingent talk</u>: No modification suggested; recognized need to keep conversation short during structured large group activity</li> </ul> <p><b>Small-group book sharing</b></p> <ul style="list-style-type: none"> <li>• Discussed compromise of reading to half-class rather than small groups</li> </ul> <p><b>Semi-structured group activity</b></p> <ul style="list-style-type: none"> <li>• Developed generic conversation starters to encourage decontextualized talk</li> </ul> <p><b>Meal times</b></p> <ul style="list-style-type: none"> <li>• No modifications discussed</li> </ul>
Re-assessment: 1 week		
<ul style="list-style-type: none"> <li>• Child language assessments</li> <li>• Teacher Interviews</li> </ul>		



Table 1: Summary of research activities (continued)

<b>Phase 3: Retrospective analysis: 8 weeks</b>	
<ul style="list-style-type: none"> <li>• Re-analyzed data</li> </ul>	<p><b>Whole-class book sharing</b></p> <ul style="list-style-type: none"> <li>• <u>Decontextualized talk</u>: Teachers engaged in high levels of decontextualized demands (above 30%) before and after book sharing but it led to less talk <i>after</i> book sharing; increased length of book sharing may have caused teachers to limit talk after book sharing.</li> <li>• <u>Semantically contingent talk</u>: Activity doesn't led itself to extended discussions <u>Interview</u>: Teacher believed children need to develop cognitive skills; Parapro believed children needed to learn to sit quietly to prepare for kindergarten</li> </ul> <p><b>Small-group book sharing</b></p> <ul style="list-style-type: none"> <li>• Implementing half-class book sharing somewhat feasible, may need more time to fully integrate <u>Interview</u>: Teacher somewhat concerned about too many teacher-led activities</li> </ul> <p><b>Semi-structured group activity</b></p> <ul style="list-style-type: none"> <li>• Some activities allowed for decontextualized talk and child-led conversation. In general, talk focused on helping children and managing the materials. <u>Interview</u>: Activities allow children to develop other important skills/abilities</li> </ul> <p><b>Meal times</b></p> <ul style="list-style-type: none"> <li>• Teacher had conversations with children; parapro allowed children to talk and primarily responded to comments/questions; school rule hindered intervention <u>Interview</u>: Teacher and parapro still concerned that children eat nutrition meals but more open to socializing</li> </ul>



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## The Development of a Comprehensive Vocabulary Instruction Program for Nine- to Eleven-Year-Old Children Using a Design Experiment Approach

James Baumann, Camille Blachowicz, Ann Bates, Char Ciepły, Patrick Manyak, Heather Peterson, Jeni Davis, Justin Arner, & Michael Graves

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## 2. The development of a comprehensive vocabulary instruction program for nine- to eleven-year-old children using a design experiment approach

James Baumann, Camille Blachowicz, Ann Bates, Char Cieply, Patrick Manyak, Heather Peterson, Jeni Davis, Justin Arner & Michael Graves

### Abstract

*This chapter describes a design experiment exploring the feasibility of implementing a multi-faceted, comprehensive vocabulary instruction programs in classrooms in U.S. elementary schools. The study was a collaborative effort among university and school (teacher) researchers. The three-year funded project involved annual replications of the vocabulary program, which included the following four facets, or components: (a) provide rich and varied language experiences, (b) teach individual words, (c) teach word-learning strategies, and (d) foster word consciousness. The program was tested and modified on the basis of the annual cycle of Program and Professional Development, Feasibility Testing, Analysis and Program Revision. Revisions also occurred and from year-to-year across the term of the study. Results revealed that students demonstrated substantial growth on several quantitative vocabulary measures within and across years of the inquiry, with qualitative data documenting the modifications and improvement of the program as the experiment unfolded. The researchers learned that a long-term, collaborative design experiment on an instructional intervention that is conducted with classroom teachers is complex, time-consuming, and demands significant amounts of support and professional development for the teachers in order to be successful. However, the insights provided by the teacher, co-researcher's insider perspective are invaluable in understanding how to iteratively modify an intervention across time to enhance the impact and success of the new instructional curriculum.*

### 1. Introduction

The purpose of our educational design experiment was to develop and refine a comprehensive vocabulary instruction program for teachers to use with children in fourth- and fifth-grade (ages 9 to 11) elementary school classrooms in the United States (US). We had a two-part rationale: (a) there were many extant research-based individual strategies for teaching vocabulary, but (b) there was little research demonstrating if and how a balanced set of vocabulary strategies could be incorporated into a multi-faceted vocabulary instruction program.

#### Numerous research-based vocabulary instruction strategies

Decades of research in the field of reading and language education has established the efficacy of many specific types of vocabulary strategies and approaches (see research reviews by Baumann, Kameénui, & Ash, 2003; Blachowicz & Fisher, 2000; Graves & Silverman, 2010). For example, Beck and McKeown (2007) documented the efficacy of a Text Talk program for teaching children word meanings during read alouds. Scott and Nagy (2004) reported on the effectiveness of a program of word consciousness for promoting teachers' vocabulary

instruction and students' word learning. Manyak (2007) demonstrated the effectiveness of teaching students sophisticated words that described the traits of characters in narratives. Additionally, there are a plethora of research findings that document that students learn word meanings incidentally by reading independently (Swanborn & de Glopper, 1999), by listening to texts read aloud (Elley, 1989), by listening to texts read aloud supplemented by brief definitions (Biemiller & Boote, 2006), and through exposure to enriched oral language (Dickinson, Cote, & Smith, 1993).

### **Few comprehensive vocabulary instruction programs**

In spite of the voluminous literature on the effectiveness of many vocabulary strategies, few studies have looked at multiple dimensions of vocabulary instruction that could be practically and feasibly implemented by classroom teachers (National Institute of Child Health and Human Development, 2000). Although there have been a few attempts to integrate several strategies into a single program (e.g., Baumann, Ware, & Edwards, 2007; Snow, Lawrence, & White, 2009), most interventions were limited in scope, duration, or ecological validity. Pressley, Disney, and Anderson (2007) expressed this situation well:

*"We think it is time to move beyond the study of individual mechanisms [in vocabulary instruction] and ask whether evidence-based vocabulary instruction and curriculum packages can be developed that will make a difference in real classrooms. Such instruction will be multicomponential and longer term than any of the vocabulary instruction addressed in experiments to date (p. 226)."*

Because of the need for long-term research on multi-faceted vocabulary instruction programs, we applied for and were awarded a US Department of Education Institute of Education Sciences (IES) research grant to develop an educational intervention (Baumann, Blachowicz, Manyak, Graves, & Olejnik, 2009-2012). Over the three-year period of this inquiry, we developed, evaluated, modified, and re-evaluated several times a vocabulary intervention we referred to as Multifaceted, Comprehensive Vocabulary Instruction Program (MCVIP). In this case study chapter, we describe the background, critical features, development, iterative evaluation, modification, and results of our design experiment on MCVIP.

Our design experiment was a development study, which "aim[s] towards design principles for developing innovative interventions that are relevant for educational practice" (Plomp, 2009, p. 23), as opposed to a validation study, which "focus[es] on designing learning environments or trajectories with the purpose to develop and validate theories about the process of learning and how learning environments can be designed" (Plomp, 2009, p. 23). The desired outcome of our design experiment was to develop and refine a comprehensive vocabulary instruction program for preadolescent students and their teachers through multiple implementations over an extended time. The research involved three recursive phases: Program and Professional Development, Feasibility Testing, Analysis and Program Revision. These phases were replicated during each of the three years of the project. This structure is displayed in Figure 1. Our iterative development process was driven by the following research question: *How might the theoretically and empirically based MCVIP be developed and evaluated iteratively such that the program is likely to produce substantially better student outcomes relative to current vocabulary education practice?*



Figure 1: MCVIP intervention development as three phases

## 2. Theoretical and methodological framework

In this section, we provide the empirical base for our study, describe the chain of reasoning (theory of change) that guided our investigation, explain our perspective on what a design experiment entails, and express the methodological framework that undergirded our study.

### Empirical base

MCVIP was based on Graves's (2006;) four-component vocabulary program, which, as shown in Figure 2, included "(1) providing rich and varied language experiences; (2) teaching individual words; (3) teaching word-learning strategies; and (4) fostering word consciousness" (Graves, 2006, p. 5). These four components have been acknowledged to be theoretically essential components of a balanced, all-encompassing vocabulary instructional program (Blachowicz, Fisher, Ogle, & Watts-Taffe, 2006; Stahl & Nagy, 2006).

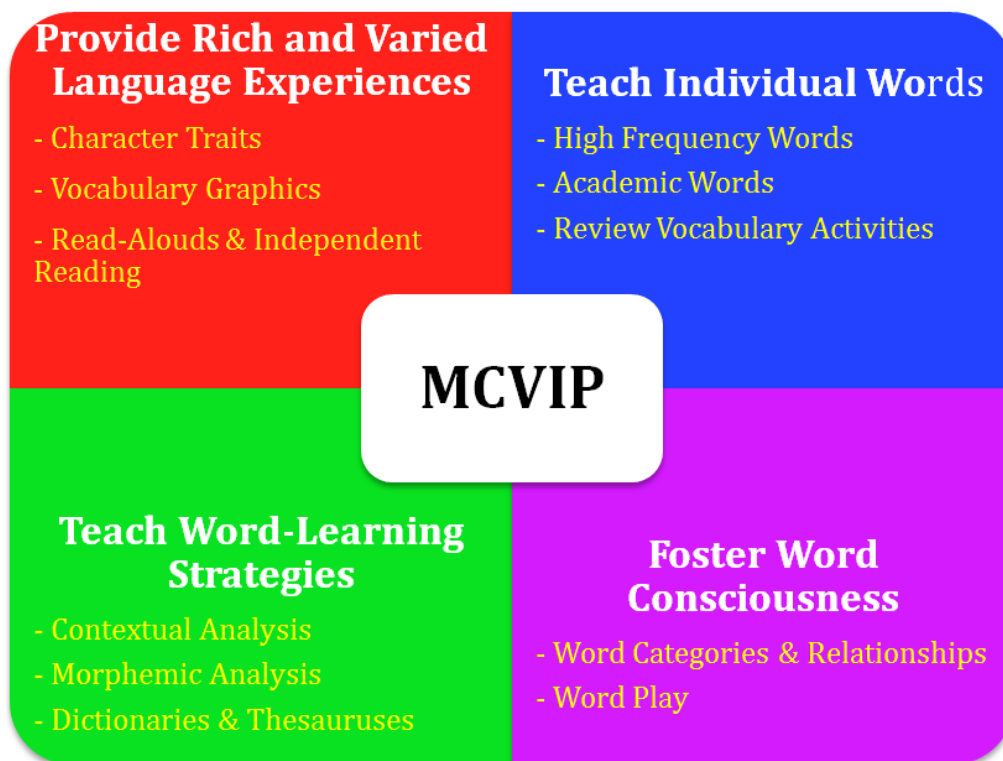


Figure 2: Multifaceted, Comprehensive Vocabulary Instruction Program (MCVIP) components, strategies, and activities

Additionally, each component possessed its own empirical base. For example, the Teaching Word-Learning Strategies component provided students instruction in skills they could use for independent word learning, specifically, the development of morphemic analysis and contextual analysis. *Morphemic analysis* involves “deriving the meaning of a word by examining its meaningful parts (morphemes), such as root words (or base words), prefixes and suffixes (collectively affixes), inflected endings, and Latin and Greek word derivatives (word roots)” (Baumann, Edwards, Boland, & Font, 2012, p. 143). A number of studies have demonstrated that when students are taught the meanings of prefixes, suffixes, word roots, and a strategy for how to use word-part knowledge when encountering unfamiliar words, students acquire the ability to infer word meanings from morphemic clues (Baumann, Edwards, Boland, Olejnik, & Kame’enui, 2003; Baumann, Edwards, Font, Tereshinski, Kame’enui, & Olejnik, 2002).

*Contextual analysis* involves inferring the meaning of a word “by scrutinizing surrounding text for syntactic and semantic linguistic cues provided by preceding and succeeding words, phrases, and sentences” (Baumann et al., 2012, p. 143). Again, there is substantial research that documents the positive effects of teaching students to recognize and use context clues (Baumann et al., 2002, 2003; Fukkink & De Gloppe, 1998;). There are similar theoretical rationales and empirical bases for the Teach Individual Words, Provide Rich and Varied Language Experiences, and Foster Word Consciousness components of MCVIP (see Baumann et al., 2009-2012).



### Theory of change

Our funding agency, the US Department of Education IES (IES), requires researchers to provide a theory of change (IES, 2012), which is the theoretical and empirical rationale for the development of an intervention and how the intervention has the potential to affect student outcomes. This theory of change (TOC) is akin to the “explicit chain of reasoning” the editors of this volume request for each case study.

In our design research, our TOC was rather straightforward. As shown in Figure 3, the TOC involved three components shown vertically: the target population, the immediate student outcomes, and the long-term student outcomes. Specifically, as shown in the first column, the target population was 9-11 year-old children who experienced the MCVIP intervention. The immediate student outcomes (column two) were data from assessments on each of the four MCVIP components, that is, data from tests for each facet of MCVIP displayed in Figure 2. The final column presents the long-term outcomes - a generalized increase of vocabulary ability - which corresponded to a standardized measure of reading vocabulary that was independent of program content. Thus, the TOC outlines how the impact of our intervention for our target population was evaluated for both immediate or “near transfer” effects and long-term or “far transfer” measures of the impact of MCVIP.

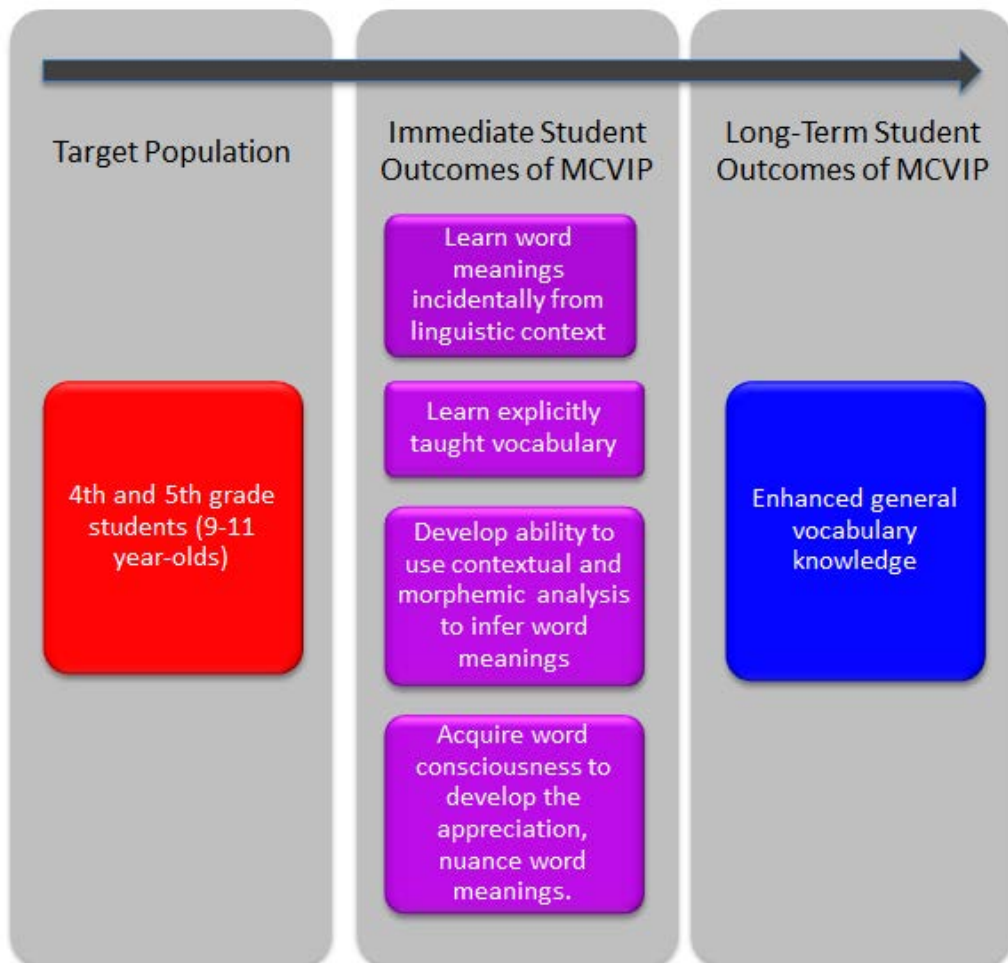


Figure 3: Theory of change (explicit change of reasoning) in MCVIP

### **Design experiment perspective**

Our design experiment perspective is based on work in the US on formative experiments in literacy research as articulated by Reinking and Bradley (e.g., Reinking & Bradley, 2008). Formative experiments are typically grounded in the work of Brown (1992) and Collins (1992) and reflect the frustrations researchers had experienced when employing conventional positivistic or post-positivistic experimental or quasi-experimental research when exploring educational interventions or innovations (see Reinking, 2011). Reinking and Bradley et al. (2012) describe *formative experiment* as an "*instructional intervention introduced into authentic instructional settings [that] is modified formatively based on qualitative, and occasionally quantitative, data indicating what is or is not working and why. . . . They [formative experiments] are guided predominantly by the pursuit of accomplishing a specific pedagogical goal through an intervention that can be justified as showing promise in accomplishing that goal. Although general research questions may guide data collection, the central focus is on determining how the intervention can be designed formatively to achieve that goal.* (p. 411)."

Reinking (2011, p. 14) argued that "improving human wellbeing is the central imperative of education research" and that the family of formative or design experiments (which he fundamentally equates, see Reinking & Bradley, 2008, Chapter 2) provides an alternative to traditional experimentation as a more direct mechanism to improving teaching and learning.

Design experiments initially had greater prominence in the arenas of science, mathematics, and technology education (e.g., Kelly, Lesh, & Baek, 2008) than they had in reading and literacy education. Recently, however, there have been a number of instances of published formative or design research studies in our field (e.g., Baumann et al., 2007; Ivey & Broaddus, 2007; Jimenez, 1997; Neuman, 1999). It also was encouraging that the US Department of Education acknowledged the value and legitimacy of funding our development project that employed the formative/design methodology (Baumann et al., 2009-2012) in light of the recent emphasis on *scientifically based research* as articulated in the No Child Left Behind Act of 2001.

Before proceeding to a description of our inquiry, we wish to make two important points. First, as Reinking and Bradley (2008) and Bradley, Reinking, Colwell, Hall, Fisher, Frey, and Baumann (2012) have argued, we fundamentally equate formative experiment and design experiment. Therefore, we will use *design experiment* in the remainder of this chapter given the title of this volume and the more widespread usage of *design experiment*.

Second, although collaboration among researchers and "participants" - oftentimes university researchers and classroom teachers, respectively - is typically a characteristic of design experiments (e.g., Cobb, 2000), there are different views on the nature and degree of collaboration. For example, Reinking and Bradley (2008), who themselves include collaboration as a typical characteristic of design research, state that "we do not believe that it is necessary to consider all formative and design experiments to be collaborative research in the strictest sense" (p. 80).

We acknowledge that design experiments can, do, and probably should vary significantly in the degree of collaboration depending on the nature of the study, research questions, and context. In our recent research, however, collaboration between our initial etic (university, "outside") and emic (classroom, "inside") perspectives grew incrementally over several years to approaching full co-researcher status (Davis, Baumann, Arner, Quintero, Wade, Walters, & Watson, 2012), much like classroom/university teacher-research inquiries do (Ware, Mallozzi, Edwards, & Baumann, 2008).

Therefore, the design research we describe in this case study grew into a highly cooperative inquiry over the period of the experiment. Out of respect for all research participants in our design experiment, we will refer from this point forward to researchers as either *university researchers* or *school researchers*. We acknowledge, however, that the latter term applied to teacher participants only *later* in the study and that the degree of investment of our teacher participants as “school researchers” varied somewhat across individuals and research sites. Nevertheless, as the study unfolded, there were genuine feelings of synergism among participants within the research sites, and this even extended across sites as the school researchers met and interacted with one another at several professional meetings.

### **Methodological framework**

Reinking and Bradley (2008, Chapter 2) describe and compare various methodological frameworks for conceptualizing, planning, conducting, and reporting formative and design experiments (e.g., Bannan-Ritland, 2003; Brown, 1992), along with their own framework. For our study, we relied on the Reinking and Bradley framework, which consists of six questions they pose for design experiment researchers to address before, during, and after their inquiry.

1. What is the pedagogical goal to be investigated, why is that goal valued and important, and what theory and previous empirical work speak to accomplishing that goal instructionally?
2. What intervention, consistent with a guiding theory, has the potential to achieve the pedagogical goal and why?
3. What factors enhance or inhibit the effectiveness, efficiency, and appeal of the intervention in regard to achieving the set pedagogical goal?
4. How can the intervention be modified to achieve the pedagogical goal more effectively and efficiently and in a way that is appealing and engaging to all stakeholders?
5. What unanticipated positive and negative effects does the intervention produce?
6. Has the instructional environment changed as a result of the intervention? (Reinking & Bradley, 2008, pp. 74-78).

We have addressed Reinking and Bradley’s questions 1 and 2 thus far in this chapter. In the following section on “Design Experiment Implementation,” we discuss the development, feasibility testing, and analysis and revision phases of our design experiment, which addresses questions 3 and 4. In the final section of this chapter, “Reflections,” we address questions 5 and 6 as we report on the immediate and lasting effects of MCVIP.

## **3. Design experiment implementation**

In this section, we present our research methods and implementation of the study. This includes a description of our research sites and the three cyclical, iterative phases that defined each of the years of our design experiment: (a) Program and Professional Development, (b) Feasibility Testing, and (c) Analysis and Program Revision (Baumann et al., 2009-2012).

### **Research sites**

Our MCVIP design experiment was conducted in research sites in the US states of Colorado, Illinois, and Missouri. In Year 1, seven classrooms participated in MCVIP in Year 2 there were 11 classrooms; and in Year 3, there were 12 participating classrooms. Data were ultimately gathered over the three-year period of the study on 606, 9- to 11-year-old children (US Grades 4 and 5) and on 15 different classroom teachers (school researchers) who participated in the project (most school researchers participated for two or three years).

Each year of our research, which was on a US school calendar (September through the following August), consisted of three phases: (A) Program and Professional Development, (B)

Feasibility Testing, and (C) Analysis and Program Revision (see Figure 1). These phases corresponded to the months of September-October, November-April, and May-August, respectively, with the exception of Year 1 when we extended Phase A to provide sufficient time to finalize research site participation, create the first iteration of MCVIP, prepare assessments, and create a variety of research protocols.

In Year 1, our research sites were in Colorado and Illinois. The Missouri site was added in Year 2 and continued in Year 3 because the principal investigator moved to a university in that state and initiated a third research setting. Our site sampling provided for the variation in geography and socioeconomic variables that we desired in our study. The Colorado site was in a suburban school in a Latino diaspora community, with approximately 75% of the children in the school being English learners with Spanish being their heritage language, with about 80% being eligible for free- and reduced-price lunch (a US index of child poverty). The Illinois research site was in an urban school of families of mixed socioeconomic status and ethnicities, with a poverty level of over one-third. Additionally, there was diversity in heritage languages and dialects at the school. The Missouri site comprised a school was in a mixed neighborhood of primarily White and African American students with a poverty level of 57%. There were few English learners at the Missouri site.

In the following three subsections, we describe the phases of our design experiment depicted in Figure 1. Although we have attempted to organize our comments such that they fit neatly within each of the three phases; in reality, that is not possible, and it is probably contradictory to the philosophy of a design experiment. As design experimenters understand, whatever phases they use to organize their studies, the processes of development, feasibility testing, and analysis and revision are neither linear nor discrete. We include within each subsection data and descriptions of events from all three years of our inquiry. We do this for efficiency in presentation, although we acknowledge that this masks to some degree the evolution of MCVIP over the full duration of our experiment.

Several researchers have attempted to represent the complexity of the iterative process in design experiments as cycles of development and evaluation activity (e.g., McKenney, 2001, as displayed in Plomp, 2009, p. 14). In addition to the phase structure shown in Figure 1 that we use to organize the following discussion, an alternative graphic that builds on the cyclical nature of design experiment is a vertical helix (see Figure 4). In this conception, the Program and Professional Development → Feasibility Testing → Analysis and Program Revision cycle repeats itself as researchers spiral vertically through time in a design experiment. Even this conception has limitations, for as we experienced in our own study, there were times when we were already making revisions as we were developing procedures, and we were revisiting professional development during feasibility testing.

Although our primary research question about enhanced student vocabulary outcomes in comparison to current vocabulary practices remained unchanged throughout the three years of the inquiry, the more specific driving research questions varied somewhat by year. For example, in Year 1 our question was, *Can* we develop the MCVIP intervention and determine if it was feasible to implement by our school researchers? After learning in Year 1 that we *could* indeed develop and implement MCVIP in Grade 4 and 5 classrooms, our questions transitioned in Years 2 and 3 to the *nature* and *nuance* of the intervention.

For example, we asked, How can we enhance the effectiveness and efficiency of the specific instructional strategies or routines embedded within each component? What is the ideal balance of time and emphasis among the components? and How can we refine our professional development approach?

With these caveats in mind about the complexity of design experiments, we turn to a description of the phases of our design experiment on vocabulary instruction.

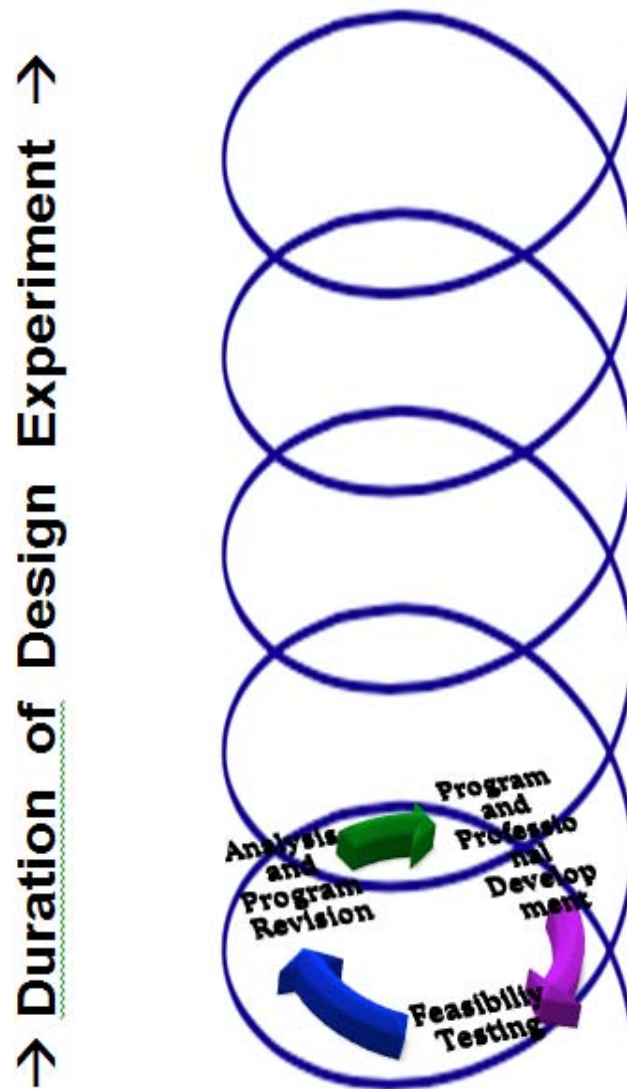


Figure 4: MCVIP intervention development as cycles in a helix

### **Phase A: Program and professional development**

The initial tasks of the university researchers in Year 1 were to fully articulate the MCVIP intervention beyond the original research proposal and to begin the first iteration of professional development with the participating classroom researchers. One of the first tasks was to establish schedules for regular professional development at each site.

These typically included both regular before- or after-school meetings, as well as longer meetings on half or full days when substitutes released the teachers from their classrooms. For example, the Missouri site ended up scheduling before-school, hour-long meetings every other Friday, with monthly all-day-long meetings at the home of one of the university researchers. Somewhat different models evolved for the Colorado and Illinois sites, but there was considerable time dedicated to MCVIP professional development at each research site.

Initially, the professional development involved introducing the school researchers to the rationale behind and the specifics of each MCVIP component and the strategies and activities devised to implement that component. For example, at the beginning of the first year of implementation, the university researchers explained the purpose of the High Frequency Words (HFW) component. This involved some “homework” (i.e., readings) for the school researchers prior to the meetings, at which there were discussions and some role-playing of how to teach the HFW lessons. Subsequently, the university researchers taught HFW lessons to the children in their classrooms as the teachers observed. Still later, the school researchers video-recorded their own teaching, which they viewed for personal reflections and which they shared at research team meetings for group discussion and critique.

This professional development structure and process were replicated during Year 1 of the intervention as each new component and associated strategies and activities were introduced. The sequence of introducing MCVIP components was generally the same across sites, beginning with the Teach Individual Words Component, followed by Provide Rich and Varied Language Experiences, Teach Word-Learning Strategies, and Foster Word Consciousness. As the professional development matured within and across years of the experiment, the introduction of components was accelerated because the university researchers had begun to refine the professional development content and process. Additionally, when school researchers continued with the program for a second and sometimes third year, they introduced the components more rapidly because they were more familiar and comfortable with MCVIP.

The amount of time the university researchers spent on professional development remained consistent across the three years of the experiment, but the emphasis of the professional development changed to more sophisticated discussions of how to enhance the MCVIP components and instruction. Additionally, as we have noted, as the experiment unfolded, the school researchers took a more active role in the professional development, often initiating topics, setting agendas, leading discussions, and sharing video and artifacts that they developed to enhance program effectiveness.

As the professional development matured in Years 2 and 3 of the study, so did MCVIP itself. When the university researchers introduced the components and received feedback from the school researchers and from researchers at the other sites (see following Phase B discussion), so, too, did MCVIP mature. Thus, the tasks of professional development and program development - particularly as they were repeated across years of the study - became simultaneous and symbiotic.

Figure 2 presents MCVIP in its fully evolved form at the end of the three-year experiment. As can be seen, each of the four components was manifest in two or three instructional strategies or activities.

To illustrate the substance of MCVIP, we describe the *Teach Individual Words* component, which included the following three specific subcomponents:

- **Teach High Frequency Words** that appear regularly in written text across multiple genres but go beyond the highest frequency words (e.g., basic sight vocabulary). For example, some of the fourth-grade high frequency words include *struggled*, *worthy*, *prevented*, *vast*, and *rational*-words that appear commonly in written texts but which students may not know or know only in a limited fashion.
- **Teach Domain-Specific-Academic Vocabulary**, which are words and expressions found in textbooks and other curricular materials that are essential for understanding and learning the content. For example, several MCVIP teachers taught a science unit titled *Nature Unleashed*, during which they taught academic vocabulary like *organism*, *population*, and *ecosystem*, which enabled students to understand and learn the science content.
- **Vocabulary Review Activities** are essential for long-term learning. For example, MCVIP teachers use Word Walls and other tools (e.g., Smartboards, rings of word cards of words taught, dictionaries and thesauruses, games and other activities) to provide students regular review of words that had been introduced and taught. (from Baumann et al., 2012, <http://vocablog-plc.blogspot.com/2012/10/mcvip-multi-faceted-comprehensive.html>).

There is not space in this brief case study to present in detail all MCVIP components, so we refer readers to the web site referenced above, which describes all four MCVIP components and the strategies and activities nested within each, along with graphics and examples of program feature. Readers interested in additional details can refer to several applied publications that address MCVIP strategies or approaches directly or some akin to them (Baumann et al., 2012; Blachowicz & Baumann, 2013; Blachowicz & Fisher, 2012; Graves, Baumann, Manyak, Blachowicz, 2013; Manyak, 2012).

Before moving to our discussion of Phase B Feasibility Testing, it is important to state that not all four components of MCVIP were implemented identically in all research sites. Given that one of our goals was to determine the feasibility of implementing MCVIP in multiple educational contexts that varied in curriculum, instructional materials, and assessment, specific MCVIP strategies and activities were employed somewhat differently across sites. For example, the Illinois school had a mandatory core reading program that required those researchers to integrate the word-learning strategy instruction (i.e., the contextual and morphological analysis lessons) into the adopted reading program; thus, they taught embellished word-learning strategy lessons as they appeared in the core program. In contrast, there was not a core reading program that was strictly followed at the Colorado school, so the word-learning strategy lessons were taught intensively and separately of the core curriculum. In spite of the variation in how the MCVIP program was implemented, however, all participating teachers and students -regardless of research site - experienced the full richness of the vocabulary curriculum.

### **Phase B: Feasibility testing**

Within the design experiment framework, we employed a balanced, simultaneous, mixed-method (Tashakkori & Teddlie, 1998) approach to data collection and analysis. Specifically, we gathered pretest and posttest quantitative summative data (annually) on student growth and development.

We also gathered significant amounts of formative (ongoing) qualitative data on students' and teachers' participation in MCVIP. We point out that the quantitative data addressed our primary, overarching summative question about the feasibility of MCVIP in producing substantially better student outcomes relative to current vocabulary education practice.

Our qualitative data, on the other hand, not only informed our primary research question but also addressed our evolving questions about the formative nature and nuance of the intervention. In this section, we use our qualitative data to illustrate how the school and university researchers' insights led to formative modifications of the MCVIP program. In the following Phase C section, we share how the quantitative functioned as summative assessments in our design experiment.

We noted previously that our professional development of the HFW included considerable observation, critique, and feedback on the implementation of this aspect of MCVIP. For consistency, we follow up with the HFW component to demonstrate how school researchers informed the study and how they and the university researchers discussed and negotiated the HFW vocabulary instructional component (Blachowicz, Bates, & Cieply, 2011; Blachowicz, Baumann, & Manyak, 2012).

After several weeks of implementing the HFW strategy during Year 1 of MCVIP, the school researchers consistently expressed frustration about time. One school researcher commented, "It takes me a long time to do this and I don't know how to simplify it [teaching HFW]." A school researcher from a different site stated, "There is no way I could have done the [all the] HFW. . . . I'm not having time. We have intervention half an hour every day with a different class then we switch for science and social studies and vocabulary." Another teacher stated: "Keep it [HFW] to only 4 words a week or less. 5-6 words were too many."

There also was a common belief that students knew many or even most of the HFW prior to instruction: "These are pretty easy words," one school researcher commented. Another stated that "Some of the HFWs have less appeal than [other] words for my students" The grouping structures also caused some consternation, with one school researcher stating, "I don't like large groups. It takes too much time away from differentiation," with another saying, "I don't like [the] small group. It takes too much time."

Our approach was to acknowledge teacher frustrations with HFW (and with other components when they occurred) and to ask the school researchers to specify the problems, which they gladly did:

- "Sometimes the definitions are not kid-friendly enough."
- "The second day's lesson where we read the phrases should be modified."
- "Could we connect it [HFW lessons] more to the curriculum? . . . Seems sort of random and disconnected."
- "[We need] more student engagement."
- "It was hard having *rare* and *unique* together in Lesson 15. They confused them."
- "I'd like to look at other activities for Day 2 [of HFW] instead of reading the story."

The university researchers didn't always agree with the expressed concerns (e.g., the suggestion to teach only 4 HFW per week), and sometimes they argued that a "problem" was more of an opportunity (e.g., capitalize on the similarity between *rare* and *unique* to distinguish and teach their subtle meanings and use). But the university researchers listened and worked with the school researchers to improve the HFW lessons. For example, in response to frustrations expressed by the school researchers, one of the university researchers stated:



*"I hear what you are saying here. Let's not kill HFW but figure out how to teach them more efficiently. . . . We are still committed to the HFW [but if teaching them] really gets problematic, we want to hear [from you]. . . We are going to modify the lessons. . . . We might have a couple of little models, or a couple of scenarios for how to [teach the lessons]."*

The research team brainstormed ideas and modified the lessons on the basis of teacher input. For example, the school researchers made suggestions like upping the pace ("going faster in the HFW lessons"), adding examples ("coming up with a sentence to demonstrate knowledge of the word"), making connections for the students ("after giving definitions, I always give personal connections"), using the HFW electronic whiteboard lessons better ("talking about the picture first [and] then showing the [example] sentences"), and getting students more involved ("I have made the HFW lessons more interactive to increase student interest and participation by asking students to stand up, sit down, put their hand on their head when they know an answer").

On the basis of this feedback, the research teams modified the HFW lessons several times and in many ways, capitalizing on the craft knowledge and experience of the school researchers while utilizing the understanding of sound vocabulary instruction the university researchers possessed. Consequently, the skepticism and frustration school researchers initially expressed changed. The teacher who had stated "these are pretty easy words" later commented, "I thought they knew all these words but they DON'T know them. Like *aquatic*. I was floored." One teacher had inquired early in the HFW introductory phrase, "How are we going to get the kids to USE those words?", but she stated later, perhaps begrudgingly, "Well, I am going to have to like this component [HFW] because I am seeing that it is helping my students."

We saw other changes, too. Early in the school year, a teacher who was new to MCVIP was skeptical when we asked her to use dictionaries and thesauruses as part of our Word-Learning Strategy (WLS) component. She stated, "Kids in this grade can't use dictionaries. It just takes too much time." Later in the year, she acknowledged, "Well, they really seem to like them and USE them. I'm kind a getting into this. They are starting to use them on their own for the games." At the end of each school year, we conducted student focus groups to obtain their opinions of MCVIP. When asked what kind of advice students would give teachers about using MCVIP the next year, one fifth grader responded, "Don't resist the dictionary!"

Not all challenges and problems were solved immediately, and some -such as how to identify and teach academic vocabulary from the specific curriculum at each site -persisted for quite some time. As the design experiment progressed within and across years, however, the teachers realized that they had a say in the study, and an esprit de corps grew among research teams. Problem-solving became an enticing challenge. Near the end of the study, one school researcher commented, "I really appreciated the constant dialogue and reflection that occurred between all member of this research team." Another classroom research stated that "I felt that I have been part in the creation of lesson plans and the sequencing of the different MCVIP components. . . . I also feel that my feedback is listened to, scrutinized, and sometimes utilized for the betterment of the program."

### **Phase C: Analysis and program revision**

The quantitative data from our mixed-methods design experiment provided us formative and summative information about the degree to which students were developing word knowledge and word-learning strategies. Quantitative data were gathered each year for all participating students on five beginning-of-school-year (fall) pretests and on a corresponding set of end-of-school year (spring) posttests.

These included four experimenter-constructed proximal assessments, which were the (a) Specific Vocabulary Knowledge Assessment (SVKA), which assessed students' learning of words that had been taught explicitly (e.g., HFW); (b) Context Analysis Assessment (CAA), which evaluated students' ability to use context clues to infer the meanings of low-frequency words; (c) Morphemic Awareness Assessment (MAA), which assessed students' knowledge of morphemic elements and their ability to use that knowledge to construct the meaning of morphemically "decodable" low-frequency words that were devoid of context; and (d) Word Consciousness Assessment (WCA), which included a rating-scale open-ended questions that required students to self-assess their vocabulary knowledge, explain how they dealt with unknown words, and to demonstrate various aspects of word consciousness. These measures correspond to the Immediate Student Outcomes column in Figure 3. A standardized measure, the Vocabulary subtest of the Gates-MacGinitie Reading Tests (GMRT) (MacGinitie, MacGinitie, Maria, & Dreyer, 2002), served as a distal measure, which corresponds to the Long-Term Outcomes column in Figure 3. All but the WCA lent themselves to inferential statistical analyses, which we address here.

All experimenter-constructed and standardized measures had strong reliabilities (coefficient alpha), ranging from a low of .767 to a high of .941, with a median of .890. To evaluate quantitative growth, we conducted a series of paired-sample *t*-tests. Results from the SVKA, CCA, MAA, and GMRT demonstrated that student outcomes on the spring posttests were statistically significantly higher than their performance on the fall pretests. This was true for all three years, and many effect sizes (Cohen's *d*) were in the medium to high range. For example, the effect sizes on the SVKA, which assessed words that we taught explicitly in the program that included the HFW, were quite impressive at Year 3 ( $d = 1.381$  for Grade 4 and  $d = 1.181$  for Grade 5).

The quantitative measures not only documented that students who experienced MCVIP grew in vocabulary statistically significant levels, but they also guided our annual formative revisions of the program. For example, the effect sizes for the word-learning strategies after Year 1 of the program were only modest in size (CCA  $d = .378$  and MAA  $d = .561$ ). At the end of Year 3, however, for the CCA and MAA were .549 and .830, respectively, documenting that we were able to enhance students' ability to use word-learning strategies *across* the duration of the design experiment.

The general summative measure of reading vocabulary, the GMRT, which did not test words that were taught in MCVIP, also demonstrated a clear trend that students' yearly growth increased across the years of the inquiry. Specifically, effect sizes on the Extended Scale Scores (ESS) of the Vocabulary subtest GMRT were .322, .413, and .485 across years 1, 2, and 3, respectively.

We also noted that growth tended to accelerate across the three years of the design experiment. For example, when comparing the grade equivalent (GE) scores that corresponded to the means of ESS, which can be compared across levels and grades for a given test, we found that the GE scores revealed about one year's growth on the GMRT for Years 1 and 2. However, the fourth-grade pre/post GEs for Year 3 were 3.4 and 4.7, respectively, and the Grade 5 pre/post GEs for Year 3 were 5.3 and 6.8, respectively. This suggested that it took the school and university researchers up to three years to develop MCVIP to the point that it that demonstrated substantial student growth in vocabulary.

In summary, our Phase A experiences revealed that an intensive professional development program could be developed to provide school researchers the support they needed to initiate and sustain their commitment to MCVIP.

The Phase B formative qualitative data demonstrated how researchers collaborated to improve the components of MCVIP to create a feasible vocabulary intervention. Finally, the Phase C formative and summative quantitative data indicated that the program development, feasibility testing, and revisions in Phases B and C enhanced student vocabulary development from year to year and accelerated their growth as the program grew to maturity.

#### **4. Reflections and lessons learned**

Reinking and Bradley (2008) ask design experimenters to consider whether there were unanticipated positive or negative effects from the intervention implementation, which we interpret as “lessons learned” from the study. In terms of potential negative effects, we found in the first year of the program in particular that success in implementing several components had a deleterious effect on other components. Our emphasis on explicit vocabulary instruction in the Teaching Individual Words component (i.e., the HFW and academic vocabulary lessons) and the intensive Word-Learning Strategy lessons we provided in that component reduced time available for teachers to address the other two components. Initially, we did not engage much in the Foster Word Consciousness dimension of MCVIP, and teachers tended to skip time for student independent reading and teacher read alouds in the Provide Rich and Varied Language Experiences component because of demands in keeping up with the other components.

This was troubling, for we knew that the aesthetic aspects of word consciousness and the essential reading practice and exposure to text provided by these missing components could have increased students’ independent vocabulary learning and interest and motivation in vocabulary. Once we recognized this problem, we sought a better balance among the four components, but it was worrisome that we may have inadvertently created a vocabulary deprivation situation as we strove to enhance explicit vocabulary instruction. This lesson was not lost throughout the remainder of the program as we tried to “put MCVIP in its place,” by which we meant that all classroom and university researchers needed to remind themselves that word learning is just one part of a literacy curriculum and that the literacy curriculum is just one aspect of a total educational program.

Reinking and Bradley’s (2008) final question-Has the instructional environment changed as a result of the intervention?-is another way of exploring what we learned from the study specifically and more generally lessons learned about design experiments. With respect to Reinking and Bradley’s question, we are confident that it has and in positive ways. Our school researchers became celebrated in their buildings and districts for their expertise in vocabulary instruction. Teachers from other buildings visited their classrooms and observed their vocabulary lessons. Additionally, principals at the participating schools became interested in expanding MCVIP to other grades, and the researchers received requests to work with teachers in other schools in the districts.

Vocabulary became an indispensable part of the school researchers’ curriculum and instruction. Collaboration was central to the success of the program. The classroom researchers and university researchers created an intervention that would not have been possible outside the design experiment paradigm. The synergy was palpable, as is evident in one of the classroom teacher’s comments near the end of the research:

*"I know I have grown as a teacher because of this study and feel that it is greatly because of the coaching from the team, the implementation and reflection of lessons, and the freedom to go back into my classroom to try something in a different way."*

We do not wish to romanticize our experience, for we learned that the university researchers made mistakes; there were false steps, pitfalls; and both university and school researchers experienced more than a bit of frustration along the way. Developing interventions is challenging, complex, and at times, quite messy. However, did MCVIP change the instructional environment? We believe that the answer is revealed by statements from our school researchers, one of whom stated, "This research team has made me look at vocabulary differently and enhanced my teaching. I will never look at words the same and have this research team to thank for that." When a university researcher asked, "What is your opinion of MCVIP now [at the end of the study]?", one school researcher responded, "Would never not teach it," after which a colleague added, "[I will teach MCVIP] even when our grant is over. I still have kept copies of everything. I can't imagine not teaching it now. I don't know how we did without it. I love it; the kids love it."

Now that the three-year design experiment has concluded, the university researchers still hear from school researchers. These have included brief emails such as, "I miss MCVIP! I have already taught the first 2 HFW lessons and 1 CT lesson. We should all get together soon!" and "Missing you all this year!!! =)". We also have received more in-depth emails from post-MCVIP school researchers, such as the following:

*"I can't express how much I miss working with the MCVIP team this year. Alas, reality has set in. However, vocabulary instruction is going great with my new class. . . . We have 3 students that are pushed into our class with autism only during vocabulary. Their SPED teacher specifically wanted vocabulary time because she had observed MCVIP lessons taught last year. . . . [Name of fourth-grade colleague] and I have also been training the other two 4th grade teachers how to instruct vocabulary with MCVIP. They are 100% on board! If there is any way I can collect data or anecdotes for my 3rd year teaching MCVIP [this teacher participated in MCVIP for two years], please let me know. . . The last 2 years with MCVIP were priceless to me!"*

In sum, it seems to us that something about MCVIP has stuck and lives on in the classrooms of our design research colleagues.

### **Author notes**

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## Design of a Primary School Physics Web-based Learning Environment: The Teacher's Role in the Educational Design Research Project

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# 3. Design of a primary school physics web-based learning environment: The teacher's role in the educational design research project

Kalle Juuti & Jari Lavonen

## Abstract

*Educational design research (EDR) appears in authentic teaching and learning situations. Therefore, the teacher's role needs to be taken into consideration during the EDR process. In this chapter, we describe one of our EDR project called Astel. We have understood EDR from the point of view of pragmatism. In collaboration with teachers, we designed, tested, and evaluated a web-based learning environment for primary school physics. By describing the process, design solution, as well as the main data gathering and analysis, we illuminate the different roles of the teachers in EDR project. Our main argument is that the researchers' attitudes towards the teachers have to be collegial as they both have the same goal. Teachers and researchers are co-designers of innovations that aim to develop teaching.*

## 1. Introduction

One aim of this chapter is to describe one of our design research projects called Astel (Juuti, 2005) as an illustrative case of educational design research (EDR). Within the Astel project, we designed via an iterative process a web-based learning environment for primary school physics. Educational design research appears in authentic teaching and learning situations (Brown, 1992; Edelson, 2002). Therefore, teachers should have a crucial role in the research process (Engeström, 2011). Thus, in addition to describing the EDR project, this chapter also aims to highlight the tension between different possible roles for teachers in the EDR project. We have interpreted educational design research in the context of science education research in a pragmatic framework (Juuti & Lavonen, 2006). In a very concise form, we emphasise the following aspects of the pragmatic framework. Dewey, one of the classic pragmatists, viewed knowledge as an organism-environment interaction. "In brief, the environment consists of those conditions that promote or hinder, stimulate or inhibit the characteristic activities of a living being. A being whose activities are associated with others has a social environment. What he does and what he can do depend upon the expectations, demands, approvals, and condemnations of others. A being connected with other beings cannot perform his own activities without taking the activities of others into account" (Dewey, 1916/1980, pp. 15-16). In pragmatism, knowledge and action are seen to be intimately connected. Knowledge emerges when a designed innovation is implemented in a classroom. Further, through reflection, knowledge is gained from experiences of classroom implementations (Juuti & Lavonen, accepted). The knowledge formation is seen to be tightly connected to authentic teaching and learning situations. Therefore, teachers are needed to engage in educational design research projects. We apply Dewey's notion of shared activity as a conceptual tool to analyse our Astel-project.

Dewey uses the notion of shared activity in differentiating situations where one “does not share in the social use to which his [or her] action is put” (Dewey, 1916/1980, p. 17). In situation involving shared activity, one has “the same interest in its accomplishment which others have. He [or she] would share their ideas and emotion” (Dewey, 1916/1980, p. 17). In educational design research, shared activity means that teachers and researchers design, implement, and evaluate educational innovations together; thus shared activity requires communication between teachers and researchers. Biesta and Burbules (2003) characterise communication as a process involving “the mutual coordination of action, and therefore, it is not a process in which a teacher simply reacts to a researcher’s movements, after which the researcher reacts to the teacher’s reactions, and so on. Dewey’s point here is that successful coordination requires that the teacher reacts to what the researcher intends to achieve with his activities, just as the researcher reacts to what the teacher intends to achieve with his activities. Successful co-ordination requires that the partners in interaction try to anticipate the other’s actions” (Biesta & Burbules, 2003, p. 41).

In what follows, we first describe the Finnish educational context. After that we focus on the process of our educational design research project. We summarise the designed learning environment, data gathering, analysis and results. We hope that the description of the project will illuminate the possible ways to collaborate with teachers and engage them in the shared designing of learning environments.

## **2. The context of Finnish primary physics teaching and learning**

The teaching profession in Finland has always enjoyed great public respect and appreciation. Parents and policy makers trust Finnish teachers as professionals who know what is best for children. Finnish teachers are expected to design and evaluate teaching. There is no national testing, school inspection or pre-examination of textbooks. In Finland, in accordance with the regulations of the National Core Curriculum, local education providers (municipalities) and even schools and teachers are allowed to plan the local curriculum. They are also free to choose learning materials and teaching methods. An important reason for this high status is that primary teachers have been educated since the beginning of the 1970s in Masters level programmes at universities (Lavonen & Juuti, 2012).

When the Astel project began physics did not exist as a separate subject at the primary level, and it was limited to a part of a school subject called environmental and natural studies. There was a need for knowledge of how to implement physics in primary schools. Further, there was a lack of learning materials in primary school and learning materials. Consequently, we decided to design a specific learning environment in order to learn about primary school physics teaching and learning and offer research-based information for national level curriculum development. Later, a subject called Physics and Chemistry was introduced in the Finnish core curriculum (FNBE, 2004). Thus, at the beginning of the project we were in a situation of ‘do not know how to act’. Teachers did not know how to teach physics at the primary level and we as researchers did not know about primary physics teaching in the Finnish context and what kinds of teaching and learning materials or learning environments could help Finnish class teachers in their new situation.

The core curriculum for physics emphasises awareness of the pupil’s previous knowledge and an experimental approach as a starting point for teaching and learning primary physics. Its objective is that physics should be taught in a practical manner and pupils should practise the experimental method by studying suitable natural phenomena in grades 1-6. Pupils should also be able to plan and carry out simple experiments or investigations into natural phenomena.

### 3. The process of the educational design research Astel

The design team was made up of the following experts: one professor specialising in science education and another one in ICT use in education, three senior lecturers (two specialising in physics education and one in chemistry education). As a result of external public funding, it was possible to invite two primary school teachers, one web designer and one graphic designer to join the design team. The requirement of the sponsors was that the designed learning environment should be available for teachers without any fee.

At the beginning it was agreed that members of the design team had to put aside their beliefs about science learning, engagement and learning environments and had to become familiar with research into those topics in general and especially from the point of view of science learning (as described in the Section 'literature review'). Secondly, the design team had to become familiar with primary school teachers' needs and their circumstances, especially of ICT use in science education (see the Section 'teachers' view'). The design procedure was easily agreed upon: the participating teachers' role was to be in charge of manuscript writing and organising classroom tests in collaboration with the researchers. The researchers' responsibilities focused on arranging interviews, planning prototype testing, and analysing the data for re-design suggestions. Researchers also participated in designing the learning environment. Especially, researchers read the manuscripts and commented on these, based on findings from the classroom tests and research literature. Moreover, everyone in the designing team participated in the brainstorming processes.

There were several groups and responsibilities in the project:

- managing (three members)
- designing additional information for teachers: teachers' physics learning materials (three responsible members)
- teachers' teaching model materials (two members)
- pupils' study materials (four responsible members)
- the graphical user interface (two responsible members).
- the research activities were designed and coordinated in parallel with graphic designing and manuscript writing (four responsible members).

Each design team member had at least one specific area of responsibility. It is important to note that only two persons were working full-time on the project: the classroom teacher who wrote the manuscripts and was not teaching during that academic year, as well as the graphic designer.

Typically, meetings where the whole research group was present were organised once a month (during the active phase of the project), and included the following features: 1) project management, 2) research, 3) project update, 4) discussion and evaluation of drafts and the generation of new ideas, and 5) action plans. The project was not for profit and was funded by several parties. Therefore, it was crucial to ensure that all the parties agreed on common goals and procedures (cf. Lavonen & Meisalo, 2002). It was important that all the parties saw the benefit of every participant involved in the project. In addition, management decisions were made during the meetings to ensure that the resources of the project (sponsors or competence) were balanced. The form of the project was novel to everybody as no one really owned the designed learning environment. All parties were cooperating towards shared goals.

In the project, a web-based learning environment for primary school physics was designed, implemented and evaluated. Our educational design research was intertwined in the design process of the learning environment. There were three designing and piloting phases including data gathering and analysis in order to inform the re-designing. Table 1 summarises the iterative design research process. We arranged classroom testing of the very first drafts of the



manuscripts for the learning environment. Therefore we had the opportunity to make major changes for the learning environment during the project. In what follows, we describe in more detail the educational design research project Astel and highlight the role of teachers during the process.

Table 1: Summary of the iterative design research process

Phase of the research project	Research question	Data gathering	Results	Implementation
Teachers' views:	What are teachers' needs for a primary physics learning environment?	Primary school teachers wrote essays on the subject "How I see myself as a physics teacher" Three "different" teachers were interviewed	Teachers emphasised student activation, reliable subject knowledge, high usability, high quality illustrations and support for planning of teaching and learning	Environment should have several activities (games, paper-pencil tasks, practical work activities). Layout of the web-pages should be simple, emphasis on clear illustrations, a web-form for questions.
Testing 1 (one double lesson <sup>1</sup> , one class, one topic)	What are the major problems in using the initial prototype of the learning environment?	Observation notes, video observation, reflective discussion after the pilot	Unsatisfactory connection of physics models to observations while students engaged in practical activities. Teacher's role is important in classroom management	The first prototype had separate practical work and content knowledge modules. They were integrated as "knowledge and investigations".
Testing 2 (eight double lessons, one class, all topics)	How do pupils engage in learning and how do they feel about the pleasantness of learning?	Student questionnaire, interviews (two pair of students)	Pupils seemed to enjoy learning; they acknowledged the possibility to listen to the stories. Physics is seen as only relating to school.	Learning path - guide for teacher in order to help to focus on "physics around us" module as well.
Testing 3 (three double lessons, Three classes from different schools, altogether 77 students and three teachers)	To what extent did students learn Newtonian mechanics? Is there a gender difference in conceptual learning?	Observations, Conceptual understanding test (modification of FCI-test <sup>2</sup> )	Minor conceptual learning occurred. There were differences between classes. Classes that applied background stories achieved better than a class without applying stories.	Role of the narratives in science teaching and learning needs to be more acknowledged in research and teaching of primary physics.

1. One lesson is 45 minutes of teaching, double lesson is about 90 minutes.
2. Force Concept Inventory, see Hestenes, Wells, Swackhamer, 1992.

### **A literature on issues supporting primary school physics learning**

Sandoval (2004; 2013) emphasises three aspects of learning environment design: 1) Embodiment of learning theories (activity structure and social participation structures), 2) observable outcomes of teaching and learning in the designed learning environment, and 3) learning outcomes. According to him, there should be a connection between these three aspects. During the educational design research, the embodiment needs to be changed if the expected outcomes have not been achieved. Therefore, the first task in educational design research is to clarify what is known about learning about the topic (in our case Newtonian mechanics at the primary level) and clarify how it is believed the learning goals can best be achieved. Our starting point was the learning environment literature for ICT and science education (e.g Meisalo & Lavonen, 2000; Voogt & Van den Akker, 2002)

We grounded our design upon ideas that the learning environment should engage pupils in tackling the topic to be learnt in such a way that they create meaningful and understandable knowledge structures in accordance with the goals set for learning. This type of meaningful learning is founded on activity and intention, reflection and self-evaluation, collaboration and interaction, construction, contextualization, and cumulative learning (Bransford, Brown, & Cocking, 2000).

Activity and intention means that pupils take responsibility for their own learning; they set their learning goals together with a teacher and act in accordance with these goals. Research into collaborative interactions indicates that successful collaborative learning is facilitated by the co-regulated engagement of the group in the shared problems; pupils should be encouraged to take part in group activities where they support each other by discussing and sharing knowledge. Since pupils actively build new knowledge based on their previous knowledge while learning, tailored information helps them to construct comprehensible structures. The importance of relating learning to authentic contexts, like real-life situations or simulations, is emphasised. This in turn presupposes that the learning setting allows for such learning experiences. Since learning is cumulative, pupils should be supported in their understanding of how a new concept is related to their already familiar network of concepts. These characteristics of meaningful learning form a set of criteria for designing artefacts and for planning the teaching and learning activities where the artefacts can be used.

In the case of the learning environment described in this chapter, the main aim was that the designed artefact was in accordance with the forthcoming National Core Curriculum. From the point of view of physics learning, we followed the recommendation of Hestenes (1992) who suggests applying qualitative models as a means to organise the content to be learned. Models are used to represent and explain the observed phenomena in school laboratories and everyday life situations. However, one of the key questions is how to formulate models for pupils aged 10 to 12 and how the models are to be introduced to the pupils, as well as how the pupils can be encouraged to discuss, present explanations and test their models. According to Vosniadou, Ioannides, Dimitrakopoulou and Papademetriou (2001) the conceptual change could be facilitated through encouraging pupils to take active control of their learning themselves and express their ideas, as well as to support the ideas of others, make predictions and hypotheses, and test them by conducting experiments. This can be understood as one form of inquiry-based science learning (e.g. Andersson, 2007). It is also valuable that they study in small groups, discuss, and use models and representational symbols in experimenting, doing measurements and sometimes also presenting their work to their classmates for debate. In addition to the characteristics of meaningful learning, engagement aspects should be taken into account while designing the learning environment. However, there are several theories

concerning engagement, motivation, and interest, as well as the relationships between them and their impacts on learning. Ryan and Deci (2009) suggest that engagement should be thought of as a construct that includes subjective perceptions and behavioural actions. Moreover, basic psychological needs, the need for competence, the need for autonomy, and the need for relatedness, are important for the development of engagement in the context of self-determination theory (SDT) (Ryan & Deci, 2002). Furthermore pupils will better engage in active learning if they are interested in physics. Having a positive atmosphere in the learning environment is one important condition for encouraging interest or curiosity (Krapp, 2002; Lorsbach and Basolo, 1998). Consequently engagement, motivation and interest are important when planning the learning environment.

Finally, it is well known that science textbooks typically reinforce stereotypical gender roles (Zittleman & Sadker, 2002). Thus, one goal in the design process was to avoid gender bias and another goal was to ensure a gender sensitivity that gives boys and girls equal opportunities to participate in learning physics.

Teachers might have several strategies to avoid science at the primary level (Appleton, 2003). In the designed learning environment there have to be elements (i.e. affordances) that helps teachers to take into consideration the above aspects of physics learning. In order to understand the requirements of these elements, we interviewed primary school teachers. The final Astel learning environment, with sub-sections describing the research process, is described below.

### **Teachers' views**

At the beginning of the project, we considered whether it was important for the project team to have a detailed understanding of the primary teachers' views and expectations, and the difficulties teachers perceive in primary physics teaching and learning. By interviewing teachers we aimed to involve them in the collaborative design process and allow them to share the goals of primary school science teaching and learning. Thus, we seriously tried to take into consideration teachers' views of the goals that should be set for the web-based learning environment.

We asked 14 teachers participating in an in-service training course to write short essays about their viewpoints of physics teaching and learning. The subjects of these essays were: "How I see myself as a primary physics teacher", "What kinds of knowledge is found in physics?" and "How do pupils learn physics?" Based on the essays, we chose three different teachers for semi-structured interviews. The first teacher had only one year teaching experience, the second was very experienced, having a sophisticated view of science learning, and the third teacher viewed science teaching from the technology education point of view. Based on the literature as well as the qualitative data analysis of the essays and interviews (Patton, 2002), we defined the objectives for designing the learning environment (Juuti, Lavonen, Kallunki, & Meisalo, 2004). Following Sandoval's (2004) aspects of learning environment design, the objectives were:

1. The physics contents should be correct and up-to-date, as well as pedagogically significant and well organised. The content should be concrete, and related to the pupils' experiences in their living environments.
2. The learning environment should engage pupils in active learning. The learning environment should be easy to use. The learning environment should help teachers to introduce qualitative models of physics.
3. Pupils should learn basic models of Newton's mechanics at the qualitative (conceptual) level.

In addition, the teachers emphasised that the learning environment should offer users easy contacts with experts and peers. We were not able to successfully achieve this goal with the technology available at the beginning of the millennium.

Based on the literature, previous experiences of the design team and teachers' views, the first manuscripts of the learning environment were produced and we organised the first testing sessions.

### **First testing of the learning environment**

Based on the literature, analysed teachers' views and practical "hidden" knowledge of the members of the designing group, a prototype of the web-based learning environment for primary physics teaching and learning for grades 5-6 was designed. After the prototype was designed, we organized small-scale teaching interventions. From the pragmatic point of view, we applied educational research as a resource for reflected action to produce a situation of active, adaptive, and adjustive processes to acquire knowledge to act more intelligibly.

A teacher interacted with his pupils in an authentic classroom situation. We organised two sessions lasting two hours; altogether 58 pupils in grade 5 (age 11-12) participated in this limited use. During the testing, observation data were gathered and we discussed (interviewed) the sessions with the teacher. In the limited use of the prototype, the aim was to clarify any major obstacles that had been uncovered during the lesson. We were mainly looking for problems the students had in the implementation of the test-lessons. We videotaped the sessions and wrote observation notes. Data collection and analysis as well as findings are described in more detail in Juuti, Lavonen, Kallunki, and Meisalo (2002). Several pupils were passive or were inattentive during the learning activities, e.g. when the pupils, or the teacher, read models articles; the pupils had the possibility to play games independently, the pupils started to conduct practical work in teams, the teacher asked direct questions, or the teacher clarified content.

### **Second testing of the learning environment**

Based on reflection on the experiences from the limited use of the prototype, a revised version of the learning environment was designed. The aims of the second test were twofold: to clarify how pupils engage in learning activities and how pleasant they found learning in the designed learning environment. A class teacher, who had participated in the design of the learning environment, taught the class. The pupils were 13 girls and 16 boys in the 6<sup>th</sup> grade (median age 12). The pilot test lasted for 16 hours. We observed and videotaped two of the eight two-hour lessons. After this second test, the pupils filled in a questionnaire, which examined their interest in learning and views of the learning environment. Further, two pairs of pupils were interviewed. The questionnaires and pupil interviews are described in detail in Juuti (2005, pp. 73-82). Figure 1 is an example question from the questionnaire. There were similar questions for every module (upper) and topic (lower).

THE BACKGROUND STORY WAS



Unimportant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Important
Difficult	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Easy
Unpleasant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pleasant
Uninteresting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Interesting
No help in learning	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Helped to learn

A FORCE CHANGES MOVEMENT



Unimportant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Important
Difficult	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Easy
Unpleasant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pleasant
Uninteresting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Interesting
I did not learn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	I learned

Figure 1: Example of pupil questionnaire

Pupils evaluated the learning environment in general to be very positive. The median was four for almost every item in the questionnaire. This means that very many pupils evaluated the modules or topics to be important, easy, pleasant, interesting and supportive for learning. Girls seemed to evaluate the background story as being more important to learning (Mann-Whitney's test calculated using SPSS:  $U = 42.00$ ,  $p < 0.05$ ).

After test 2, we had a discussion with the teacher in an attempt to understand the learning process. This discussion was recorded. This reflective discussion was a form of interview with discourse between the speakers in which the meaning was contextually constructed (See Fontana & Frey, 2005). The reflective discussion convinced us to make changes to the environment. The key issues in these discussions were the teacher's intention and the pupils' actions; did pupils act in the way the teacher intended. If pupils did not act in the way the teacher intended, we (researchers and the teacher) in collaboration tried to figure out what kinds of improvements could lead to successful actions in the classroom. During the reflective discussion, we got the impression that the learning environment was too open. It seemed that when a learning environment is too open, pupils and teachers have difficulties in choosing appropriate tasks and practical work. Therefore, a teacher may 'run through' all the material and therefore there will not be enough time for discussion before and after the practical work. Further, teachers, perhaps, do not have enough subject knowledge to facilitate discussion. Therefore, we decided to design learning paths in order to offer hints for the relevant discussion topics (see the section "Properties of the learning environment").

### **Third testing of the learning environment**

Finally, after the revisions, the third version of the learning environment was tested by three teachers (field test). Teachers participating in physics and chemistry teaching in-service training volunteered for the research. Each teacher used the designed learning materials and we (researchers) observed the classroom activities, collecting field notes and video data, and moreover, analysed these data using an open coding approach. One aim of the field test was to evaluate how teachers outside the design team were able to use the learning environment. Another aim was to evaluate what and how well pupils learn Newtonian mechanics at a qualitative level. The tests were paper and pencil tests modified from the Force Concept Inventory test (Hestenes, Wells, & Swackhamer, 1992). The field testing procedure is described in detail in a monograph concerning the design process (Juuti, 2005, pp. 83-94).

We found that there were no differences between classes in the pre-test. However, there was statistically a significant gender difference in the pre-test in favour of the boys. During the field test, gender difference vanished. However, in general pupils' achievement on the post-test was not very high; the median was 50% correct (the pre-test median was 33%). Thus, only half of the pupils gave correct answers, on average, for over half of the questions. According to the analysis of the test items (Juuti, 2005, p. 91) the pupils had learned how a space rocket moves in outer space, and that objects fall to the ground at the same time. The pupils did not learn how objects move on a low-friction surface. Furthermore, the pupils seemed to have learnt a non-Newtonian model of trajectory for the flying hammer. Summing up, it can be said that pupils did not learn the force concept as an explanation for change of motion, but they learned how objects move.

Comparisons of the pupils' learning outcomes showed that our approach helped them to learn qualitative models of Newtonian mechanics. Stories appeared to have novel, non-traditional features, which benefits the learning of physics. The results of our compelling comparisons indicated that the pupils who listened (medians 50% and 56%) to the narratives learned the concepts of Newtonian mechanics better than the pupils who did not (median 31%) (Juuti, 2005, p. 93).

As we were writing this chapter, the environment we describe is being adopted in several primary schools all over Finland. According to reports received, the Swedish translation has been adopted in some schools in Sweden as well. Furthermore, at least three Finnish teacher education units have adopted the environment for the purposes of pre or in-service teacher education.

## **4. Designed Astel learning environment**

The designed learning environment contains narrative texts (figure 2), audio files, animations, exercises, colour line drawings, photos, pictures and comic-strip-like illustrations from the pupils' surroundings to help them understand basic Newtonian models (Figures 3 and 4). Graphics and worksheets for pupils to undertake practical work help teachers and pupils connect the phenomena of mechanics in real-life contexts. In the classroom, simple equipment as well as objects that are needed in practical work activities are available (See figure 5 of the tool box). The pupils are encouraged to experiment with them and to discuss their experiences. In this environment, the pupils are helped to become aware of their previous conceptions and are given qualitative models to explain the movement phenomena they have experienced. Moreover, the environment aims to support engagement, active and collaborative learning as described in the section 'A view from the literature'.

“I have never used a scooter before. How do I turn it on?” Pico asked.

“You goof! You stand on it and one leg kicks the ground to build up speed,” Sara answered, marvelling.

“OK! When a foot touches the ground, a force appears, which causes the scooter to start moving.”

Pico cheered. “Yes, I think that one could say so,” Sara said, and thought about Pico’s words. Now it was Nano’s turn to ask: “Sara, did you know that a moving object continues moving until a force stops it?” “That can’t be true!” Sara said uncertainly. “My speed always slows down and I have to kick now and then.” “It really is true,” Pico replied. “When we were on our way here in our Astel spacecraft, we took a break and went out to see the Milky Way. I teased Nano and she pushed me and I fell out of the vehicle, because I had not put on my safety belt. I moved straight forward with a constant speed. I would probably still be moving like that if that meteoroid hadn’t come along. The meteoroid moved in the opposite direction to me and we bumped into each other. The force of the clash changed the direction of my motion and once again I moved straight forward with constant velocity. Fortunately, I moved towards Astel. I was safe.

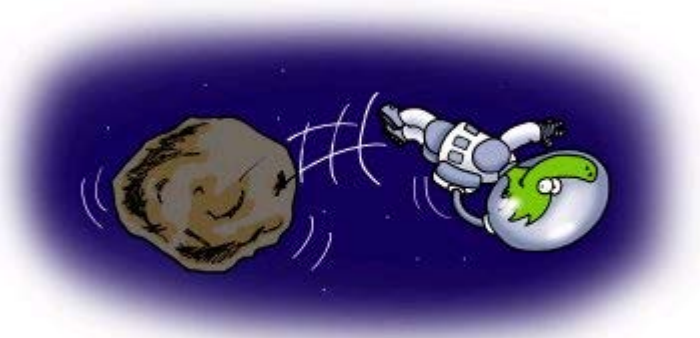


Figure 2: Translated extract of the narrative 'Force changes motion.'

In the web-based learning environment, the content was organized into four modules. Each module has its own button in the web-page (figure 3).

- *The background story* (a text and an audio file). The use of narratives is one innovation of the learning environment and it supports pupils to recognize their previous knowledge and engagement in learning. The use of narratives is to introduce qualitative models in the particular context. In the background story, two schoolchildren and the imaginary space characters Nano and Pico guide pupils through many concrete investigations to compare their own experiences with the space characters' experiences. These characters live where neither air resistance nor friction exists and the basic laws of Newtonian mechanics are met in an ideal environment allowing straightforward interpretations. Figure 1 illustrates the style of the narratives.
- *Models and practical work*. Experiments, qualitative models, animations, and exercises lead pupils to collaborate, experience, and become aware of the experiences and explain them. First, there is a short theoretical summary of the situations and phenomena described in the story (Figure 4). Below the summary, there are inquiry activities. There are also animations from the situation under discussion to prompt discussion before or after practical work is completed. These modules help pupils to connect physical phenomena with the models describing them. They are consequently traditional in nature, similar to a textbook. The basic models of Newtonian mechanics that are included in the Background stories are again emphasised in the phenomena, models and experiments module of each content item. Our goal is that pupils learn to recognize phenomena (that belong to a certain area or module of Newtonian mechanics) in their surroundings; and explain those phenomena by qualitative models. In test 1 of the learning environment there were two separate modules



(1) phenomena and models; and (2) practical work. After the first test of the learning environment, these two modules were integrated as seen in figures 3 and 4.

- *Physics around us* demonstrates phenomena that can be explained by models and principles learned both in societal and in technological contexts.
- *Games and additional exercises* facilitate pupils' reviewing the topics learned.

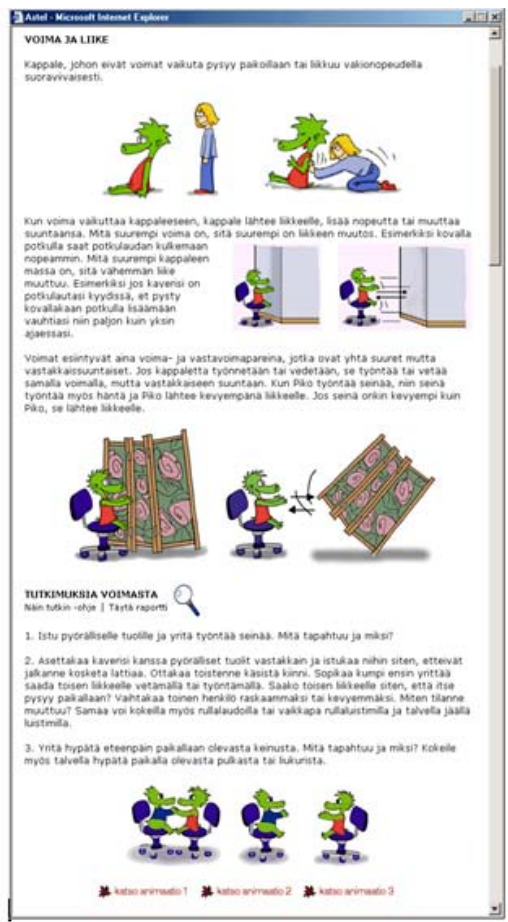
There are two modules for teachers: *Learning path and additional information*. *Learning path* introduces goals, suggested inquiry activities, and the main concepts of the topic. There are tips for discussion, and tips for scheduling. This module was designed as a solution to the problems revealed during Test 2. The *Additional information* module is more detailed and it is used in in-service teacher education. The additional information module contains subject knowledge and detailed descriptions of teaching methods suitable for physics teaching.



Index on left includes the topics: Force change motion, motion, resistance forces, mass and inertia, gravity and balance. Additional content topics are an inclined plane, lever, gear wheel, and wheel. The last topic is summary test. Further, there is index, glossary, and a link for the home page.

On the bottom, there are module buttons: *Learning path* that introduces goals, practical work suggestions, and main concepts. *Background story*, *Models and practical works*, *Physics around us*, *Additional information*, *Games and exercises*.

Figure 3: View of the topic "Gravity and balance"



Title above, *Force and motion*, is an introduction for Newton's laws in qualitative form. Emphasis is put on the Third law: action and reaction. The text connects observations and Newton's laws as explanations for the observations.

Title below, *Force investigations*, is a practical work instruction. It contains the same observations and explanations in the same and new contexts as in the model text. For example, the last task (3) is in the context of a swing.

On the bottom, there are three animations of the ideal observations.

Figure 4: Example of the Models and practical works module



Figure 5: Toolbox attached to the web-based environment

To summarize, the learning environment integrates and emphasizes three aspects in the study of Newtonian mechanics: 1) the pupils' previous informal experiences and experiences in the school laboratory, 2) the pupils' interpretations of phenomena in the background story or in animations, and 3) learning about idealized circumstances, when the space characters Nano and Pico compare their previous experiences with the school children's experiences in the background story. The aim is to help pupils to become aware of their explanation strategies and for them to see that motion and force phenomena can be well explained using the basic models

of Newtonian mechanics. However, test 3 showed that the goal of learning Newton's basic laws in qualitative form is very ambitious for children aged 10-12.

## 5. Discussion

We have described one of our educational design research projects. In this discussion we will reflect on to what extent the idea of teachers' and researchers' shared activities was realised during the research process. The types of innovations designed in the projects, like the web-based learning environment, have typically been very intangible for teachers at the beginning of a project. In the described project, we have started to work with the teachers with a very preliminary idea or with an "open" problem to be solved and, in addition, supported the establishment of an open and safe atmosphere to address the problem. These kinds of environments are essential for creating novel and innovative innovations that can solve several problems (Isaksen, 2011).

According to the pragmatic frame and our experiences, shared design work with teachers should start from the beginning of a project. At the beginning of the design phase, working with the teachers could, for example, involve an introduction to a literature review in the field of the project and mutual reflection on the participating teachers' current activities in the classroom. Immediately after completing the first prototype of the learning environment, it was important to arrange a trial in a classroom.

We consider teachers to be members of the research group or at least members of the design team. The teachers' role is to plan the teaching during the testing. A teacher knows the pupils in the class best. Therefore, it is important that teachers plan the testing. They are owners of the intervention. In order to have interesting interventions from the research point of view, teachers need to participate in the brainstorming sessions in the design phase, in the planning of the classroom testing, and in the reflection session where the outcomes of the experiment are presented and discussed. Then there is tension between the following two extremes: 1) educate teachers to plan the intervention that researcher want or 2) accept that teachers might design something different than researchers envisaged. This different design is perhaps more authentic and perhaps represent more the actual situation in schools than intervention that researchers might design alone. At least Finnish teachers are not very keen to learn directive prescription how to teach in the classroom. Therefore, designed learning environments should not be "revolutionary" requiring massive in-service training.

Critiques (e.g., Engeström, 2011) about the lack of teachers' agency in EBR projects is connected with the fact that the researchers set the objectives of the design and the teachers' role is only to adopt the designed innovation e.g. web-based learning environment. The pragmatist framework emphasises the teachers' role in the design-research project. According to our experiences, both the objectives of the EBR-project and the innovation to be designed have to be discussed and analysed together with the teachers. One of the characteristics of the shared goal setting is to listen to each other in the project meetings and, moreover, to have common brainstorming sessions. All presented views and ideas should be appreciated and they must be taken into consideration. The examining of the views and practices which are related to the activities to be designed through the use of questionnaires, interviews or observations and, moreover, discussing the outcomes of these inquiries support the teachers in their participation in the project. Teachers have a lot of hidden knowledge about practice and engaging them in planning the research instruments and interpreting the results may uncover important aspects of the teaching and learning process. We believe that this is also one way to reach the situation where educational design research is an action shared by teachers and researchers. When

teachers are considered as members of the research team, they can share their ideas and emotions (cf. Dewey, 1916/1980, p. 17).

The teachers' role in a EBR-project could be analysed also from the point of view of the teaching profession: are the teachers considered to be just implementers of an innovation or designers of an innovation (and members of the research group)? It is agreed that teachers need a firm understanding of the subject matter they teach, a basic understanding of how people learn and develop and, moreover, they should be able to teach specific subject matter to diverse pupils, manage the classroom, assess pupils' performance, and use technology in the classroom. Furthermore, they should be able to apply research-based knowledge in developing a curriculum that attends to their pupils' needs (Darling-Hammond & Bransford, 2005). In some quarters it is strongly felt that teachers should be able to consume educational research and at some level produce research knowledge (Korthagen, Loughran, & Russel, 2006). Recently, Auguste, Kihn, and Miller (2010) explained that the success of Finnish and South Korean teacher education is because of the respect given to teachers-in both countries, teaching is a career which needs academic education. Consequently, research into teacher education supports the belief that teachers have the readiness for integration into the research community. When doing educational design research in authentic contexts, classroom testing is part of students' learning according to the curriculum. Therefore, we emphasise that the teachers have to have freedom in the planning of classroom trials within the framework of research objectives or research questions. Therefore, during classroom testing the ordinary aims of teaching and the aim of research to answer particular research questions are intertwined.

The shared action of teachers and researchers is a way for the researchers to come close to the situations where - in the Deweyan sense - knowledge for teaching and learning is created. Consequently, the researcher's attitude towards the teachers has to be collegial, as the teachers and researchers are co-designers of the innovation that aims to develop teaching. In practice, this is a very demanding requirement in educational design research. The selection of teachers in the project is therefore of crucial importance. However, our design process has different phases associated with the type of innovation that is being developed in order to better understand and improve teaching and learning in authentic settings.

It is extremely challenging to organise a study for an educational design research in the Pragmatist framework. On the other hand, a successful project can offer new knowledge about teaching and learning as well as an innovation. In an optimal situation, the designed innovation will support teachers to plan and implement their teaching in a way that pupils learn better with than without the innovation.

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## South Africa: Optimising a Feedback System for Monitoring Learner Performance in Primary Schools

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## 4. South Africa: Optimising a feedback system for monitoring learner performance in primary schools

Elizabeth Archer & Sarah Howie

...while volumes of data are extruded about and from schools, teaching continues without the benefits of such data. There is still a philosophy that assumes teachers know how and what data to collect to best enhance learning, and many of these assumptions are based on folk philosophies, poor measurement, and shaky data. We still teach in a manner we did 150 years ago ... (Hattie, 2005, p. 11).

### Abstract

*This chapter describes how an education design research approach was employed to enhance a feedback system of an existing learner performance monitoring system in a number of primary schools in South Africa. The design research approach employed provided an appropriate and powerful approach to adapting, developing and optimising the feedback system and produced specific design guidelines to support other designers in developing effective learner performance feedback systems in similar contexts. The design research approach provided the opportunity to design, implement and evaluate various prototypes, which slowly started to approximate the ideal for the specific context, whilst the system functioned and served schools. The quality criteria employed in design research allowed for enhancing of specific aspects of the feedback system in a systemic manner during the various phases of the design process. The chapter deals with a number of aspects including the contextualisation, conceptualisation, each phase and cycle during the research phase, outcomes and then a reflection with the aim of illustrating the chain of reasoning for this particular design research process.*

### 1. Introduction to the problem

This chapter highlights how an educational design research approach was employed to enhance a feedback system of an existing learner performance monitoring system thereby attempting to address problems with education quality in a number of primary schools in South Africa (SA). By using the design research approach the inquiry resulted in the optimisation of an appropriate, practical and effective feedback system for SA, as well as specific design guidelines to support other designers in developing effective learner performance feedback systems in similar contexts. This chapter outlines first the problem in its context and the need for the design research approach. Thereafter the research design is described and a discussion ensues about how the research was conceptualised, including the literature review. The development of each phase of the research, including the assessment phase, is provided in summary. Then the results are discussed in terms of the outcomes of the project followed by the reflections on this case and possible lessons for other studies.

#### South African education context

SA is considered an emerging economy and is an economic leader in Africa with a GNP per capita of US\$ 3690, yet a third of nearly 50 million South Africans live on less than US\$2 per day

(UNESCO, 2007, p.229). SA has grave infrastructural and economic disparities and the legacy of the apartheid remains apparent in the education system.

Despite significant funding and increased education enrolment, the quality of education remains a concern (Taylor, Muller, & Vinjevold, 2003) in a system of 12.3 million learners in more than 26 000 schools. Nowhere is the shortcoming of education quality more apparent than in the low learner performance, especially in subjects such as Reading, Mathematics and Science. This has been clearly illustrated in SA's poor performance on international assessment measures such as Trends in International Mathematics and Science Study (TIMSS) (Howie, 1997, 2001; Martin, Mullis, Gonzalez, & Chrostowski, 2004) and the Progress in International Reading Literacy study (PIRLS) (Howie, et al., 2008, 2012). This has been further highlighted in national studies such the Systemic Evaluations since 2000 and most recently in the 2011 Annual National Assessment for Grades 1-6 (Department of Basic Education [DBE], 2011). These results have been mostly attributed to poor teacher quality and training; lack of leadership and lack of competence at all levels in the system.

Learner performance monitoring data for evidence-based practise are required in order to understand and to address the problem of continued and sustained underperformance (Brinko, 1993; Hattie, 2005; Coe, 2002). The data can, however, only have positive impact if fed back to schools and supporting education authorities who are prepared and are competent to intervene appropriately. Not all approaches to providing feedback lead to improvement of educational delivery (Kluger & DeNisi, 1996). There may be problems in communicating the data appropriately given the experience of principals and teachers. Schools often do not know how to use data appropriately and may not understand it or be unwilling to incorporate it into their decision-making process (Hattie, 2005; Schildkamp & Teddlie, 2008; Wohlstetter, Datnow, & Park, 2008). There may also not be the appropriate levels of support to design suitable interventions. Furthermore, contextual factors such as the school culture and level of data literacy of staff play a large role in determining if a feedback system will succeed (Fullan & Dalin in Visscher, 2002, p. 52).

### **South African Monitoring system for Primary schools project**

Given the South African context and the challenges of improving education quality in South African primary schools, a project called the South African Monitoring system for Primary schools (SAMP) project was initiated by the Centre for Evaluation and Assessment (CEA) at the University of Pretoria nearly a decade ago to research ways of supporting schools using evidence based monitoring of learning performance. SAMP was adapted, translated and contextualised from the Performance Indicators in Primary Schools (PIPS) from the Centre for Evaluation and Monitoring (CEM) at the University of Durham in the United Kingdom. For a full description of the adaptation, translation and contextualisation process please consult Archer, Scherman, Coe, and Howie (2010) and Archer (2010).

SAMP produces learner performance data on phonics, reading, mathematics, handwriting and English additional language for entry level learners (5-7 years of age) data are collected at the beginning and the end of the year. The data from SAMP are employed to inform individual learner intervention (development of individual development plans), classroom practice (introducing class wide activities such as a reading hour), and school level planning and action (motivating for appointment of support personnel such as occupational therapists). SAMP produces reliable and valid data for SA across the three languages in which it is currently employed, namely English, Afrikaans and Sepedi. Once the monitoring system was established to be valid and reliable in the South African context, it was essential to concentrate on how to

design and optimise a feedback system to schools so that they could benefit most appropriately from using the system in general and the learners' performance data in particular. The research described in this chapter pertains to research conducted in 22 primary schools in the Tshwane region of South Africa who had previously participated in the SAMP project. For a full account see Archer (2010).

## **2. Conceptualisation of the research**

The aim of this study was to identify and understand the characteristics of an effective feedback system and the use thereof in order to design and optimise a system that facilitated the use of learner performance data in SA within the school environment. The question clearly called for a design research approach (Plomp & Nieveen, 2009). Design research is application orientated; includes the research participants as collaborators; allows for refinement of the intervention through several iterations (De Villiers, 2005), focusses on finding real-world solutions in a complex environment and contributes to knowledge building through development of design principles (Nieveen, 1997; Richey, Klein, & Nelson, 1996; Thijs, 1999; Van den Akker, 1999). Design research was congruent with the aims of this study and provided avenues to optimise the feedback system while it was in use.

The research was guided by the following question:

*What are the characteristics of an effective feedback system and the use thereof for the design of an optimum feedback system to facilitate the appropriate use of learner performance monitoring in primary schools in SA?*

This question has been decomposed in the following sub-questions:

1. How can an existing learner performance monitoring system be adapted, contextualised and translated appropriately to the SA context?
2. What characteristics of an optimal feedback system for use in school-based monitoring are documented in literature?
3. What pre-existing conditions need to be established in the feedback system to facilitate the optimal use of the learner performance feedback system?
4. How do schools use feedback?
5. How effective is the feedback system in enhancing classroom practices, management and planning activities?
6. Which design guidelines can be identified for the development of an effective feedback intervention for school-based monitoring?

In this study, each cycle of design research consisted of the design and implementation of a version or prototype of the feedback system. Each prototype was formatively evaluated, leading to a further cycle of development and resulting in a new prototype. The following design criteria were employed in the evaluations (see Table 1).

Table 1: Criteria for high quality interventions (Nieveen, 2009, p. 94)

Criterion	
Relevance (also referred to as content validity)	There is a need for the intervention and its design is based on state-of-the-art (scientific) knowledge.
Consistency (also referred to as construct validity)	The intervention is 'logically' well-designed.
Practicality	<i>Expected</i> The intervention is expected to be usable in the settings for which it has been designed and developed.
	<i>Actual</i> The intervention is usable in the settings for which it has been designed and developed.
Effectiveness	<i>Expected</i> Using the intervention is expected to result in desired outcomes.
	<i>Actual</i> Using the intervention results in desired outcomes.

The design research process for this research comprised three phases with multiple design cycles:

- Preliminary phase (one cycle)*: This phase was designed to address research sub-questions 1 and 2.

Sub-question 1 examined how SAMP was adapted to the SA context, as part of the preparation for the Preliminary Phase. Sub-question 2 was addressed by a needs and context analysis. This included a literature review and an exemplary case study of the Assessment Tools for Teaching and Learning (known as asTTle) project in New Zealand (NZ). The quality criteria for this phase were relevance and consistency. The emphasis of this phase was to conceptualise the feedback system and define the design specifications for the feedback system.
- Prototyping phase (three cycles)*: Research sub-questions 3-4 were addressed in this phase, which consisted of the iterative research cycles during which Prototypes I-III of the feedback system were developed, implemented and formatively evaluated. The emphasis of the cycles shifted throughout the Prototyping Phase, focussing first on how to establish conditions for use in Cycles 1 (through expert evaluation reports and the Delphi technique with school users) and 2 (generated through teacher and principal questionnaires) then on how to transform these conditions for use in action in Cycle 3. Cycles 1-2 concentrated on research sub-question 3, with the evaluations concentrating on relevance, consistency and practicality. Cycle 3 examined research sub-question 4 by means of questionnaires for teachers, principals and Heads of Departments (HoDs). These were supplemented with the examination of three schools' data-use processes through observations of school meetings, reflective journals for teachers and interviews with teachers, HoDs and principals. Cycle 3 addressed the quality criteria of actual practicality and expected and actual efficacy.
- Assessment phase (one cycle)*: This phase represented the semi-summative evaluation that examined the functioning of Prototype IV as an integrated system. The phase therefore supplemented already existing data for research sub-questions 2-4, but specifically focussed on sub-question 5. The quality criteria addressed in this phase were practicality and efficacy, both expected and actual. The semi-summative evaluation was conducted through questionnaires for school management and teachers, as well as reports from

expert evaluators. This was the final phase of the design research process described here and completed in 2010 (see Archer, 2010), although there is further development beyond this project as part of the work of the CEA.

This study incorporated various combinations of qualitative and quantitative methodologies during each evaluation cycle of the prototypes (see Figure 1). The data from each evaluation served to develop design guidelines to inform the development of the next prototype, which was also evaluated. In the next section, the conceptual framework is discussed as it framed this investigation.

### **3. Development of conceptual framework**

It is important to keep in mind the overall research problem when discussing the conceptualisation (as discussed in the first section). In the South African education system there is a general problem with quality in primary schools. Although a feedback system, SAMP, had been implemented in the primary school in this study, no empirical data were available about the use of the data. Anecdotal evidence indicated that there were some difficulties with the system, but research was required to optimise the system of feedback to impact positively on the participating primary schools.

The conceptualisation of the study took place during the Preliminary Phase of this study. The quality criteria focused on for this phase were relevance and consistency. Schools participating in the existing feedback system prior to 2006 expressed a need to receive feedback more quickly and that the data be presented in such a manner that it is easier to use for planning, decision-making and action in the school environment. It was necessary to develop design guidelines and criteria for the global design of the feedback system to facilitate use of the data. In order to accomplish this, a number of approaches were employed, including literature review and investigation of selected international School Performance Feedback Systems (SPFSs). This was supplemented with an exploration of an exemplary case in the form of the aSTTle in NZ. The preliminary phase also resulted in the development of the conceptual framework for this study.

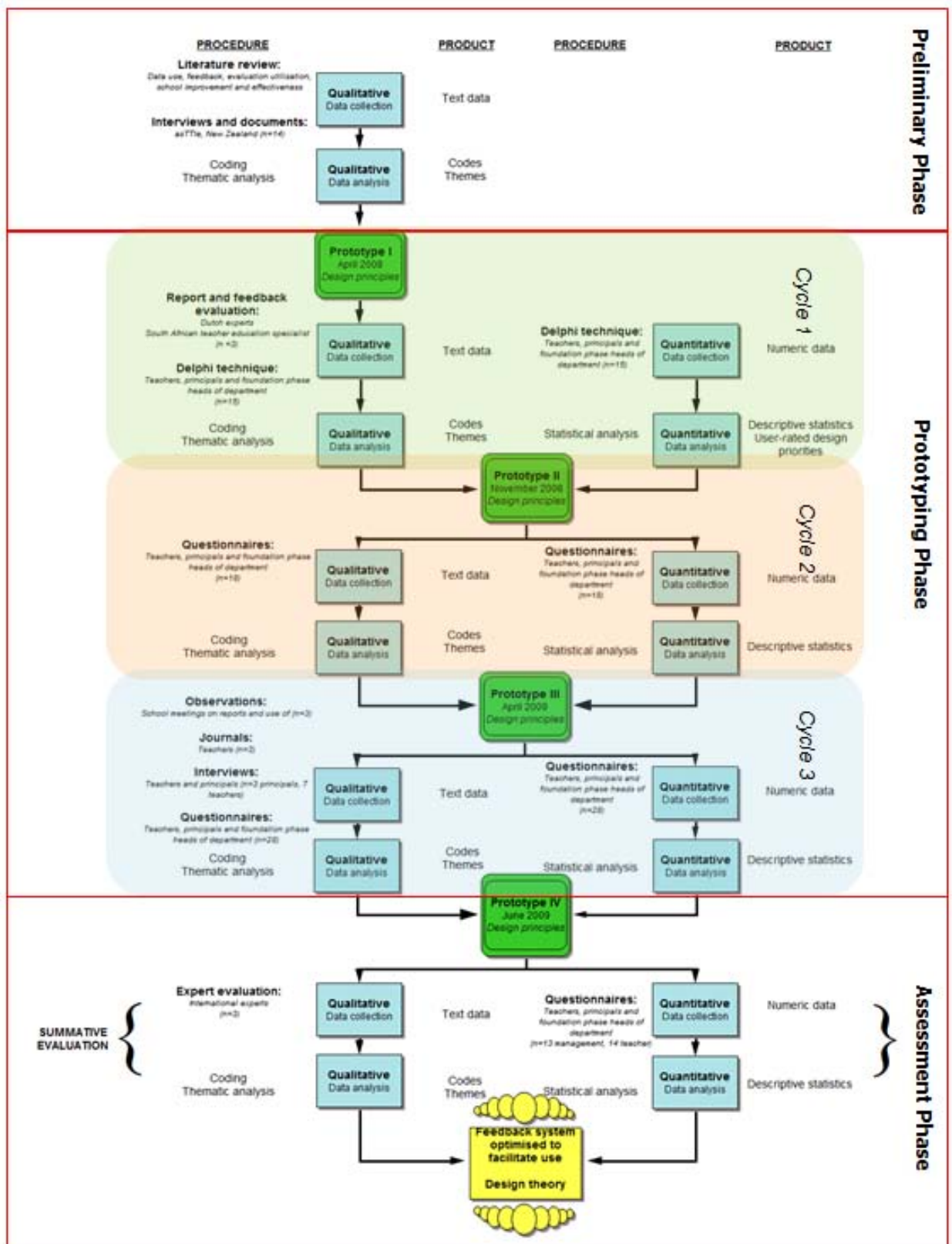


Figure 1: Research procedures



### **Analysis of the context of the problem**

The problem and context analyses for this study involved an investigation of the pre-existing feedback system employed for SAMP prior to 2006. The pre-existing system incorporated a baseline and follow-up assessment period, each of which had a paper-based report and feedback session with the schools participating in the project. The school-users (principals, teachers and HoDs) of the pre-existing SAMP system indicated that the feedback was particularly useful in terms of:

- individual learner results to compare to their own standard of marking;
- early identification of exceptional learners and learners at risk for additional support;
- having contact with the feedback system facilitators as a resource in the university context;
- supporting their understanding of the data.

A number of shortcomings were also identified, including:

- comparative data between schools was not provided on all scales;
- reporting categories were too wide to observe small changes;
- data was not detailed enough to support interventions, e.g. poor early reading scores did not indicate which aspects of early reading were of concern;
- some data presented, while interesting, had no application value;
- no recommendations were made;
- turnaround time from assessment to reporting was too long;
- individual results were not aggregated in such a way that classroom wide interventions could take place;
- communication between the schools and the previous feedback system facilitator was not optimal.

### **A review of the literature**

Based on this initial analysis of the pre-existing feedback system, a literature review was conducted to identify and possibly determine tentative design guidelines for the optimisation of the pre-existing feedback system. The literature review encompassed several knowledge domains including: School Performance Feedback Systems (SPFSs), evaluation utilisation, feedback, data-use school effectiveness and school improvement (Black & Wiliam, 1998; Hattie, 2005; Schildkamp, 2007; Schildkamp & Kuiper, 2010; Schildkamp & Teddlie, 2008; Visscher, 2002). As no feedback system existed in SA at the time of the optimisation, international SPFSs that had been documented over an extended period of time were reviewed. The four cases included the Centre for Evaluation and Monitoring (CEM) Suite (UK), the assessment Tools for Teaching and learning (asTTle) system (NZ), Zebo (*Zelf Evaluatie in het Basis Onderwijs*) (Netherlands) and School Analysis Model (SAM) (Louisiana, USA).

Although these cases have varying approaches to SPFSs, there are some common principles that emerged:

1. The data must *not be viewed as part of unfair high-stakes accountability practices* (Hattie, 2005; Tymms & Albone, 2002).
2. *School and educator expertise should be utilised in the development* and improvement of the feedback system to ensure contextual appropriateness and a sense of ownership (Hendriks, Doolard, & Bosker, 2001; Tymms & Coe, 2003).
3. The feedback system must *provide tools to support school improvement-driven practices* and support greater school autonomy (Angelle, 2004; Hendriks, et al., 2001; Teddlie, Kochan, & Taylor, 2002).

4. Data must allow for *comparison of a school's performance to other groups* (Angelle, 2004; Crooks, 2002; Hattie, 2005; Hendriks, et al., 2001; Tymms & Coe, 2003).
5. *A short turn-around time* from assessment to reporting is essential to ensure the data is still relevant.
6. *Use of ICT is important to improve turnaround time* and increase the school's sense of autonomy (Angelle, 2004; Hattie, 2005; Hendriks, et al., 2001; Teddlie, et al., 2002).

The literature on SPFSs and examination of the pre-existing system provided a rich source from which to develop initial design guidelines for the components of the feedback intervention. However, investigating contextualised processes and logistical issues through literature alone was insufficient. A case study of an exemplary feedback system, asTTle, in its context was conducted to gain deeper insight and knowledge.

### **An exemplary case study of the asTTle project in New Zealand**

The asTTle system has been described extensively elsewhere (Brown, Irving, & Keegan, 2008; Crooks, 2002; Hattie & Brown, 2008; Hattie, Brown, & Keegan, 2003) so only a brief overview is given here. AsTTle provides the autonomous, decentralised schools of NZ an educational technology resource that provides data for school, classroom and learner improvement by assessing student performance in reading, writing, and mathematics in either English or Maori. The test-users can select from a suite of graphical reports (including an online catalogue of curriculum-aligned teaching resources) that allow interpretation of the performance of individuals and cohorts relative to norms, standards, and objectives (Hattie, Brown, Ward, Irving, & Keegan, 2006).

Data for the NZ case study were collected through document analyses as well as interviews with school users, NZ Ministry of Education officials, asTTle development team members, professional developers and researchers using asTTle. Data were thematically analysed to identify the design specifications. The analysis of the exemplary case study proved to be a successful tool to identify design guidelines for the optimising of the SAMP feedback system in South Africa. The following guidelines were identified:

- The system must include: a trusted assessment system, clear reporting (e.g. reports, feedback sessions), support to understand the data, support to use the data and school relationship management.
- All aspects have to be supported by a congruent paradigm of assessment for learning (assessment to support learning, not mainly for reporting) as opposed to assessment of learning (Gardner, 2006).

The global design guidelines from the literature and the exemplary case study are summarised in Table 2.

Table 2: Combined design guidelines from the preliminary phase

Component	Case study	Literature review
<b>Instruments</b>	Use of school and educator expertise in development, to ensure contextualisation and engender trust.	Use of school and educator expertise in development, to ensure contextualisation and engender trust.
<b>Reporting</b>	<ul style="list-style-type: none"> <li>• Use multiple forms of data presentation to accommodate the needs and preferences of users.</li> <li>• Data presented in clear and easy manner, not require high level of data-literacy.</li> <li>• Short turnaround time from assessment to reporting.</li> <li>• Detailed diagnostic data.</li> <li>• Comparative elements.</li> <li>• Allow for further independent analysis.</li> </ul>	<ul style="list-style-type: none"> <li>• Provide comparative data for evidence-based decision-making.</li> <li>• Short turn-around time between assessment and reporting.</li> <li>• Use of ICT to decrease turn-around time and increase autonomy.</li> </ul>
<b>Support to understand the feedback</b>	<ul style="list-style-type: none"> <li>• Multiple forms to support understanding to suit user needs and preference may include live support, professional development and also ICT resources and printed media.</li> <li>• Some support must be available 24 hours, e.g. ICT resources or printed media.</li> </ul>	
<b>Support to use the feedback</b>	<ul style="list-style-type: none"> <li>• Multiple forms to support use of the feedback to suit user needs and preference.</li> <li>• Some support must be available 24 hours.</li> <li>• Congruence between the infrastructure, feedback and support delivery modes to ensure sustainability and accessibility.</li> </ul>	<ul style="list-style-type: none"> <li>• Resources to support school improvement based on the feedback must be provided.</li> </ul>
<b>School relationship management</b>	<ul style="list-style-type: none"> <li>• Essential and continuous process.</li> <li>• Open face-to-face communication with users engenders trust.</li> <li>• Some support should be available around the clock, even if only in printed form.</li> <li>• Must be responsive to user input.</li> <li>• Feedback facilitator reputation and persona affect the trust in the system.</li> </ul>	<ul style="list-style-type: none"> <li>• The quality of interaction between facilitator and users impact on sense of trust, ownership and credibility.</li> <li>• Communication must be honest, open, clear and respectful.</li> </ul>
<b>Supporting paradigm shifts</b>	<ul style="list-style-type: none"> <li>• System should operationalise assessment for learning to facilitate action in schools.</li> <li>• Encourage triangulation of data.</li> <li>• The feedback system must not be so technical or data-literacy demanding.</li> </ul>	<ul style="list-style-type: none"> <li>• Not be viewed as part of high-stakes accountability.</li> </ul>

### **Conceptual framework**

The literature review and case study culminated in a conceptual framework for the feedback system for monitoring learner performance. The global design guidelines discussed in the previous section relate to the feedback system component of the conceptual framework. The conceptual framework (see Figure 2) employs a systems theory approach (Greene in Johnson, 1998, p. 97; Johnson, 1998; Patton, 1997). For a fuller description, see Archer (2010).

Feedback and use are entrenched in the *external environment and context* (Shulha & Cousins, 1997). This includes the *historic, economic and political influences* such as the legacy of a highly segregated educational system and variable school infrastructure (Howie, 2002). The *educational context* relates to the educational system itself and in SA may include availability of support services, high administrative demands and a shortage of educators (Department of Education, 2006).

*Competing information* in SA includes data from international studies e.g. TIMSS and PIRLS, systemic evaluations, data from the Internal Quality Management System (IQMS) (Education Labour Relations Council, 2003), other research and monitoring activities, everyday knowledge and media reports. Either competing data sources may be integrated or selectively ignored (Hattie, 2005).

The *internal feedback context* incorporates the constantly interacting characteristics of the monitoring and feedback system, monitoring facilitator and users. The *monitoring and feedback system characteristics* include whether the methodology is appropriate for the users and context. This choice impacts how users are viewed as informants, participants or co-researchers (Cousins & Leithwood, 1986). The choice directly influences the sense of ownership of the process. If the users are uncomfortable with the methodology, it may increase resistance to use of the feedback system. Users also examine the quality of the monitoring and feedback and though they may not focus on traditional qualitative norms, they often foreground issues of relevance (Schildkamp & Kuiper, 2010).

*Monitoring and feedback facilitator characteristics*: the monitoring facilitator may take on various roles e.g. expert, facilitator, planner, or educator (Alkin & Daillak, 1979; Rossi, Lipsey, & Freeman, 2004). The facilitator's skills, social competence, contextual knowledge and technical knowledge interact with personal attributes including language spoken, culture and background to influence the facilitator's perceived competence. These characteristics often have a greater influence on use of feedback than technical competence (Taut & Alkin, 2003).

*User characteristics* include characteristics of the school and individual people in the school. School characteristics influencing use include problem solving approach and attitude towards change. The individual's approach to change, preferences of interaction style, personal motivations and how data is valued also impacts the use of feedback. As do previous experiences with monitoring and feed both personal and through vicarious learning. A common characteristic is that monitoring aimed at accountability is more likely to evoke resistance than feedback aimed at improvement (Plomp, 2009).

*Relationship flux characteristics* are a result of the user-facilitator interaction. The perception of the credibility of the researcher is constantly being evaluated and adjusted, as is the user's sense of ownership. Trust concerns are a major determinant in data use (Taut & Alkin, 2003).

The *feedback system* referred to in the figure encapsulates the idea of dialogue. Nevo's (2001) concept of dialogue highlights the interactive, two-way flow of information on a continuing basis in this case between the school users and the feedback facilitator. Substantive feedback issues include the quality of the communication products, the timeliness of reporting, quality of communication as well as the accessibility of the data.

*Process use* (Cousins & Leithwood, 1986) refers to the use of monitoring and feedback during the process of monitoring prior to final feedback of results. *Findings use* relates to use of results, recommendations and findings. Both types of use commence with enlightenment<sup>1</sup> (Owen (in Johnson, 1998, p. 103)). Enlightenment takes place through decision accretion where the user's existing knowledge is supplemented by new knowledge (Weiss (in Patton, 1997)). This information is subjectively coloured by the *political demands* such as the accountability pressures from the Department of Education. Knowledge gained may be distorted into misuses such a symbolic use, purposeful undermining of the process, legitimated use (Owen in Alkin & Taut, 2003, p. 5) or purposeful non-use of the data.

<sup>1</sup> Enlightenment is also referred to as conceptual use.

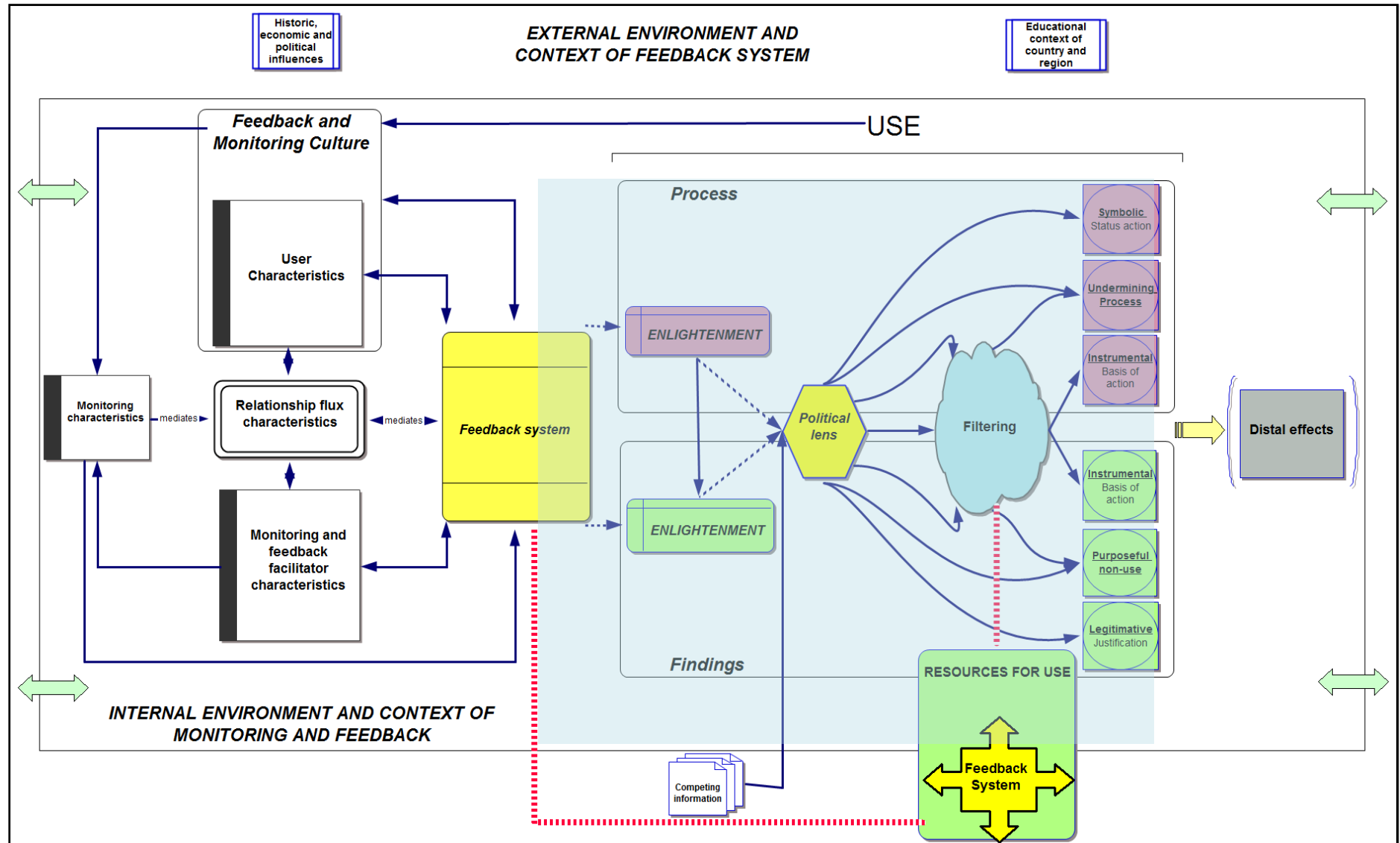


Figure 2: Preliminary conceptual framework for monitoring feedback use

Data that successfully negotiates the political lens (distortions due to pressures from the school and Department of Education) is further *filtered* through reasonability and feasibility testing. These concepts are linked to truth- and utilities testing introduced by Weiss and Bucuvalas (in Patton, 1991, p. 291). *Reasonability testing* is conducted when users quickly examine results and information to establish whether these results can reasonably be accommodated within the user's current understanding of the context and phenomena. The term *feasibility testing* relates to determining if the information gained could practically be used to bring about change. If the feedback fails either one of these tests, misuse may occur. It is only if the reasonability and feasibility testing are passed that instrumental use can take place<sup>2</sup>. After the study was concluded, the empirical data and reflection revealed that the feedback system could impact on the process of use directly at the filtering process by providing links to resources, which could positively influence whether or not the schools felt it was feasible to act on the data (this represents an additional impact of the same feedback system during a later stage of the use process).

The systems view of use acknowledges that all systems inherently strive towards a state of homeostasis (a state of stability and balance) and tend to resist change. For Fullan, (2006) the key to overcoming this resistance to change is motivating the people in the system, thus working on numerous parts of the system at once. The principle of *equifinality* also applies where changes in the system are not necessarily predictable due to the complexity of the various interacting factors and conditions and the complex feedback loops in the system (Voster, 2003).

Once the identification of the global design guidelines and development of the conceptual framework were completed, the study moved into the Prototyping Phase.

#### **4. Prototyping phase**

Three cycles of design, implementation and formative evaluation resulted in three Prototypes I-III of the feedback system during this phase. The entire design research process with the various cycles and prototypes are illustrated in Figure 3. Cycles 1 and 2 focussed on how to establish conditions for use (sub-question 3), while Cycle 3 focussed on how to transform these conditions for use into action (sub-question 4).

<sup>2</sup> The term instrumental use was first introduced in 1977 by Rich (in Johnson, 1998, p. 93) and refers to direct action based on data gained from monitoring feedback.

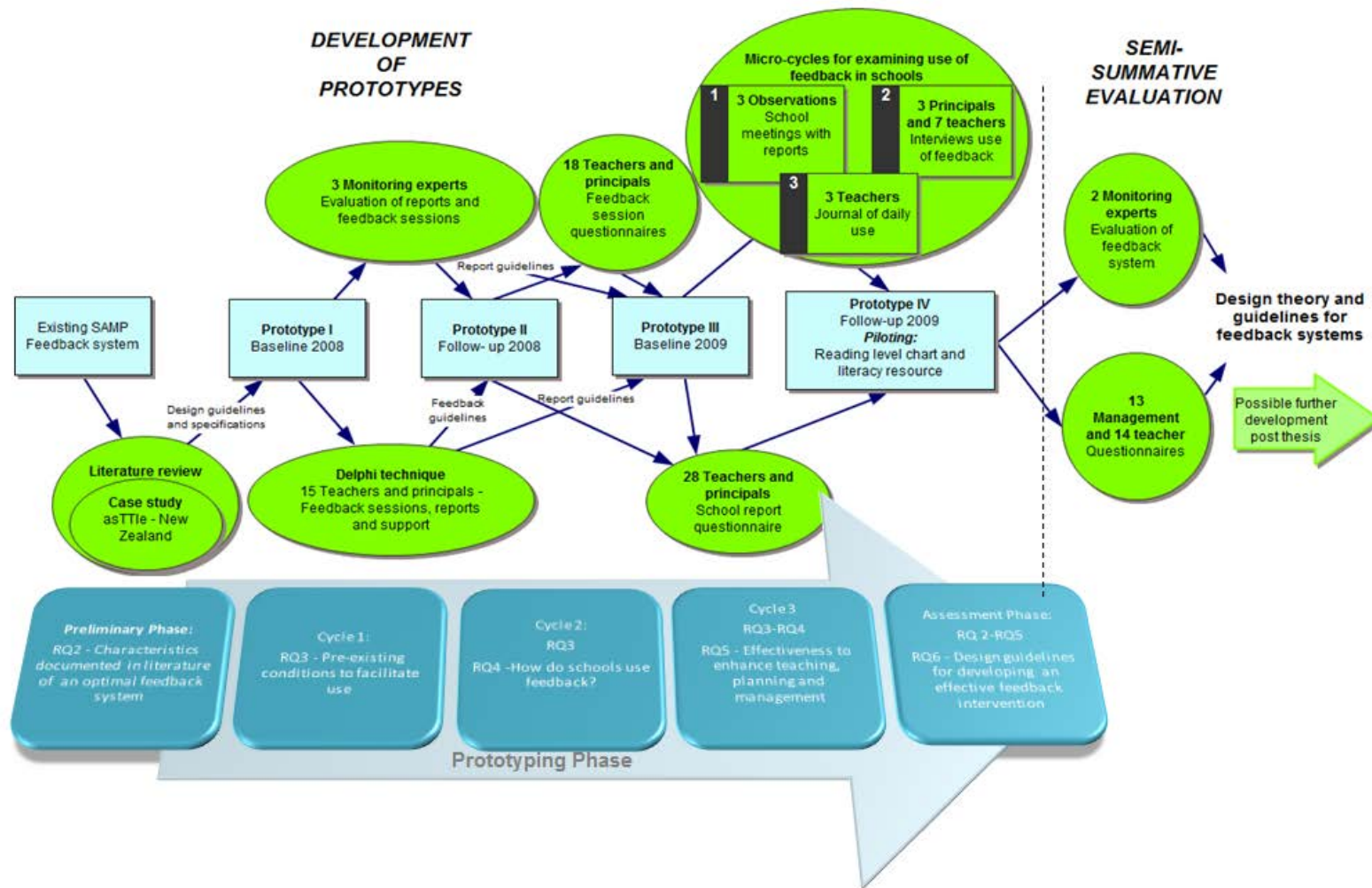


Figure 3: Design research process



### **Cycle 1 (Prototype I - Baseline 2008)**

Feedback on Prototype I was based upon the learning from the Preliminary Phase to establish the conditions for use of the feedback. The design and quality criteria for this cycle (relevance and consistency) centered on the reports and feedback session elements of the feedback system.

The formative evaluation for this cycle employed the judgements of monitoring experts (n=3) and school users (n=15). The monitoring experts were asked to evaluate the reports and feedback sessions and to provide a brief evaluation report. Teachers, HoDs and principals were asked to comment on reports, feedback sessions and support materials. Data was collected through the Delphi technique.

The Delphi technique is a group problem-solving and decision-making approach that does not require face-to-face interaction (Michigan State University Extension, 1994). A specific problem is posed and participants contribute their ideas, in this case by fax and email. This is followed by a series of carefully designed questionnaires that incorporate summaries and comments from the previous rounds to generate and clarify ideas. The process concludes with a voting round in which the participants can indicate the priorities for the specific project (Dunham, 1995; Illinois institute of technology, ND; Michigan State University Extension, 1994; Williams & Webb, 1994). In this cycle participants were asked how the use of the feedback system could be improved with specific references to the feedback sessions, reports and support for understanding the reports.

The cycle resulted in the separation of the baseline report (traditionally given to schools at the beginning of the school year after testing) into a report and separate manual. The report concentrated on the data for the specific school in contrast to the manual which focussed on the interpretation of the data and explanation of the assessment relevant for all schools. Further expansion of the manual took place, with particular reference to analysis and interpretation at subtest level, curriculum links, reliability and validity of the data from the feedback system, as well as interpretation and use of data. The feedback session with the schools was also shortened from two hours to one and some report automation (replacement of manual graph production and data transfer) took place to facilitate improved reporting turnaround time.

### **Cycle 2 (Prototype II - Follow-up 2008)**

The formative evaluation of Prototype II was more directly focussed on the feedback session and employed school-users as evaluators. The guiding research and evaluation question for this cycle was therefore still question 3 (establishing pre-existing conditions for use of data), but with a focus on the feedback sessions (evaluative criteria: relevance, consistency and practicality). The second cycle's data were generated through teacher and principal questionnaires (n=18 questionnaires).

The guidelines that were emerged from the formative evaluation for Cycle 2 all related to the feedback session. Improved turnaround time was called for in order to increase the relevance, usefulness and efficacy of the feedback. It was suggested that feedback be linked to resources (materials to support intervention, such as pamphlets and websites) and suggestions for action, while opportunities for two-way conversation between feedback administrators and school users was advocated. This could be facilitated by creating an atmosphere that is non-judgemental, constructive and invites participation. It was suggested that feedback should be clear, concise and simple (for example using bar graphs with which most teachers were familiar) so that conversation could focus on interpretation and application, not only understanding of the data.

### **Cycle 3 (Prototype III - Baseline 2009)**

For the third cycle, questionnaires (n=28) were again employed for teachers, principals and HoDs. This was supplemented with the examination of three schools' data-use processes through observations of school meetings (n=3), reflective journals for teachers and interviews (n=10) with teachers, HoDs and principals. The formative evaluation examined the functioning of the new report format and how well the feedback system facilitated the transformation of the feedback into action in schools. The aim was thus to determine how schools were interacting with the feedback and what the barriers or facilitating/enabling factors were to employing feedback in each school's specific context. The quality criteria were therefore actual practicality and expected efficacy with specific reference to the reports and manner in which feedback is used in schools.

The design guidelines for the report for this cycle advocated further improvement of turn-around time through automation, links to resources that facilitate use of data and inclusion of additional variables such as pre-school attendance to allow for additional analysis of the data. The observations illustrated that the whole system must embody assessment for data-based planning and learning. Data presentation should be such that understanding the data is easy and resources can rather be allocated to implementation. For instance, data presentation incorporated mean scores as opposed to regression lines and graphic presentations were also not complicated with measures of variation, which could prove confusing for school users. Curriculum links were intended to support data-based action as well as target setting for improvement actions and the triangulation of various data sources such as classroom assessments and SAMP data.

## **5. Assessment phase**

The final cycle incorporated the learning from all the previous cycles in order to evaluate the functioning of the feedback system as a whole. It therefore consisted of a semi-summative evaluation (Plomp, 2009) of Prototype IV. The evaluation was conducted by means of reports from expert evaluators (n=2), a questionnaire for teachers (n=14) and a questionnaire for school management (n=13). This cycle focussed on research questions 5 and re-addressed questions 2-4. The evaluation information served to provide design guidelines relating to the development of a functioning feedback system that facilitates use of the feedback, in other words, for the entire intervention. The quality criteria were on practicality and effectiveness, both expected and actual.

Prototype IV, which was implemented and evaluated in this cycle consisted of the Follow-up 2009 (report provided during the second half of the reception year which documented changes in results from the start of year or baseline assessment). All components of the SAMP feedback system were assessed for practicality and effectiveness, including the assessments themselves, the reports, instrument manual, electronic resource, support website and feedback sessions. All components were rated highly by users and expert evaluators on all aspects (appearance, clarity, need for the content, importance of the content, accessibility, ease of use and effectiveness). The cycle thus established that all the quality criteria, namely relevance (content validity), consistency (construct validity), practicality of the system, e.g. ease of use of the different components of the system such as the reports and resources and perceived effectiveness (catalytic validity in this case related to the perception of users that the feedback positively translated into improvements in their schools, class and individual support) as perceived by the users were met.

## **6. Yield of the project**

Design guidelines were developed throughout all three phases of the design research process, based on the various evaluations. The design guidelines, which encompass the characteristics of an effective feedback system and the use thereof, can be clustered according to guidelines for: instruments, reporting, support to understand data, support to use data, school relationship management and support for paradigm shift. The guidelines can also be classified as either product-related (related to the intervention itself) or process-related (related to the design process). The detailed design guidelines can be found in Archer (2010) and are only summarised here.

### **Instruments**

The data generated and to be provided through the feedback system must be shown to be reliable and to allow for valid inferences in order for a feedback system to be effective (product-related). User involvement in adaptation, translation, contextualisation, development or evaluation of instruments is strongly advised to encourage trust, credibility and sense of ownership (process-related). Data must be differential (discriminate well between high and low performing learners for each of the measured subtests) to have diagnostic value and be curriculum-aligned to facilitate using data for decision-making and planning (product-related).

### **Reporting**

User preferences should be accommodated through different modes of feedback (for example face-to-face, written and electronic) and incorporate various data representations (for example tables, graphs and text) (product-related). Data must have comparative elements (for instance measuring a school's result against those of other schools) and should be confidential (product-related). Reporting should include both positive and negative feedback and include interpretations and recommendations to support evidence-based improvement practice (product-related). Employing these guidelines decreases the demands on the statistical-literacy of the users, provides opportunities for users to improve their data-literacy and increases the school's receptiveness and responsiveness to the feedback.

### **Support to understand the data**

Incorporating various formats of data representation facilitates understanding of data, but should be accompanied by explanations, examples and support material (product-related). Support must be provided in a variety of manners such as written manuals, electronic support, web support and live interaction through feedback sessions and telephonic support, some of which should be available around the clock (product-related). This type of support provides users with the opportunity to select the most appropriate support form for them and accommodates users with different levels of data-literacy skills.

### **Support to use the data**

Once users understand the data, the next step is to use the data for improvement action in the schools. This can be supported by including interpretations, recommendations and links to tools for action in the feedback (product-related). This type of support should again be represented in a variety of modes with some support being available constantly, e.g. printed materials, electronic resources and web-based support.

### **School relationship management**

Every interaction with the schools provides an opportunity to alter perception about assessment and feedback systems and increase the receptiveness of the school users to the feedback (process-related). The quality of interactions is more important than the frequency of interactions (process-related). Communications, whether written or verbal should be clear, concise, respectful and encourage two-way communication that values user input (process-related). Fieldworker training is an essential component of school relationship management (process-related). The fieldworkers during the research project were located in the research team, once school begin to use the system independently, school users will have to be trained in a similar fashion to conduct assessments in future. A record keeping system of communications is essential to prevent duplication of communication by other team members (process-related). Professional execution of logistical matters provides an opportunity to show respect for users and improve the relationship flux characteristics between the feedback facilitator and users (process-related).

### **Support for paradigm shift**

A learner performance feedback system can be a powerful tool to facilitate paradigm shifts. In this case, the feedback system aimed to entrench certain concepts within the users: use of data for evidence-based practice; the need for differential teaching; assessment for learning as opposed to assessment of learning and greater understanding of the curriculum. Whatever the underlying paradigm of a feedback system, all the elements of the feedback system should embody this and be congruent with the other elements. For example, modeling the approach to interpretation, planning and action based on the data, can be a powerful tool to embody the paradigm and support process use of these skills in the schools (process-related).

The study showed that an effective feedback system facilitates appropriate use through a gradual process of enlightenment; is flexible and responsive to user inputs; values collaboration and includes instrument, reporting and support components in its design. An optimum feedback system also positively influences school feedback and monitoring culture by providing opportunities for positive experiences with feedback and increasing data-literacy. This improves the chances of feedback being used for planning, decision-making and action in the schools. An effective feedback system must also offer a comprehensive package of different reporting levels and modes to accommodate different users, with various levels of data sophistication, functioning in diverse contexts. The research also showed that an effective feedback system mediates thinking about educational instruction and curriculum and can therefore be a potent change agent. Use of clear, simple, intuitive data presentation in the feedback system allows for experiential learning to increase user data-literacy.

The design research approach employed in this study offers an appropriate and powerful approach to adapting, developing and optimising a feedback system. User involvement in design research ensures greater contextualisation and familiarity with the system, while engendering trust and a greater sense of ownership, all of which increase the receptiveness and responsiveness of users to feedback. Involvement of school users in this particular design research process also allowed improvement of statistical literacy skills, an opportunity to evaluate personal assessment standards and a deeper understanding of the curriculum links to particular skill sets. Finally, the research also contributed design guidelines for other developers of feedback systems, an integrated conceptual framework for use of monitoring feedback and a functioning feedback system that is now employed by 22 schools in the Tshwane region of SA.

Although the study took place in a specific region in SA with emphasis on primary schools, the design guidelines provide the opportunity for other researchers to replicate the research in other contexts. The rich descriptions of the research process (see Archer, 2010) provide the opportunity for design researchers to transfer the knowledge to different contexts. This may include replication within, for instance, different levels of the schooling system, different languages of instruction, different countries and different education systems. If the replication proves successful, analytical generalisability may be achieved, wherein it can be concluded that the results are applicable to all the successful replication contexts (Yin, 2003).

## 7. Reflection

Currently the SAMP feedback system is being further developed by the CEA to include more grade levels. A similar design research process is being followed for the further development. The use of a design research approach was highly effective for the design and adaptation of the feedback system. The design research approach allowed the opportunity to design, implement and evaluate various prototypes, which slowly started to approximate the ideal for the specific context, whilst the system functioned and served schools. This flexible iterative design process ensured that the design process remained responsive to input from user and experts alike. The need for responsiveness does however place high demands on the researcher to embrace emergent research design, which may call for adjustments in the originally planned research approach. Design research includes representatives of the target users in designing the interventions. This meant that users could feel a greater sense of ownership of the feedback system, making them more receptive and responsive to the data. The design research philosophy of viewing the users as true partners and collaborators in the design process was congruent with the collaborative approach used in the feedback system. The participation in the design research process also afforded users the opportunity for process learning about evaluation processes and furthered data-literacy of the participants. The quality criteria employed in design research allowed for enhancing of specific aspects of the feedback system in a systemic manner during the various phases of the design process. This not only ensured that all the criteria enjoyed attention during the design process, but also that there was a shift in which evaluative criteria were the focus during the various evaluative cycles. The design research approach resulted in design principles to support other feedback system designers, ensuring that the research had value beyond the context for which it was designed.

## Key source

Archer, E. (2010). *Bridging the gap: optimising a feedback system for monitoring learner performance*. Pretoria: University of Pretoria. Unpublished doctoral thesis. Retrieved from <http://upetd.up.ac.za/thesis/available/etd-02022011-124942/>.

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## Using the Spiral Problem Solving Process to Design Group Work: A Case Study of Educational Design Research in Shanghai

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# 5. Using the spiral problem solving process to design group work: A case study of educational design research in Shanghai

Nanchang Yang, Qiyun Wang & Zhiting Zhu

## Abstract

*This chapter reports a case study of using instructional strategies to promote group collaboration of lower primary school students who were learning the subject of science at Shanghai. Grouping strategies, problem design, and mediated tool design were used in this study. By following the educational design research approach, this study progressed through three rounds. The first round involved the use of a set of instructional strategies in two classes. Based on lesson observation results and the teacher's feedback, the strategies were revised and used for a different topic in one of the classes in the second round. Minor revision decisions were made and the adjusted strategies were implemented in the other class in the third round. The method of lesson observation was adopted for data collection. A survey was conducted on the two classes of students to identify their perceptions on the use of the strategies at the end of the third round. In this chapter, the lesson design ideas, implementation and findings, and revision decisions involved in each round are presented, and the survey results are reported. The yield of the study and lessons learned from this study are summarized at the end of the chapter.*

## 1. Introduction to the problem

Group collaboration becomes increasingly important in the new information society (Barron, 2000). Students need to learn how to work together when they are in schools so that they can prepare themselves for being competent in future jobs. However, school teachers often lack experience of organizing activities for group collaboration as they get used to the teacher dominated instructional approach in the classroom (Lim, 2007).

When students are put into groups and told to work together, it is most likely that real collaboration does not actually happen in the groups (Wang, 2009). From the surface level, it looks like that students sit and work together in the groups. But the extent to which group members really collaborate, help one another and learn from peers can be minimal. In real teaching practices, however, teachers often observe that students can learn from their peers and get a task done effectively if a group is organized and coordinated well. Research also shows that if a group leader specifies the role of each member clearly and coordinate their group members' effort, they have the possibility to work together efficiently (Barron, 2000). Therefore, teachers often need strategies to guide them in the design of learning tasks and group organization so that collaborative learning can happen.

This research was a validation study in nature aiming at identifying and testing instructional strategies for promoting effective group collaboration at a lower grade level in a primary school at Shanghai, China. The main research question was: *How to effectively promote group collaboration for learning the subject of Science in the context of a Primary 2 classroom?*

Effectively promoting students' group collaboration is a common need and challenge for school teachers in China. The knowledge gained from this study therefore has the potential to be applied into other subjects and other grade levels in similar contexts.

This study was conducted by following the educational design research approach (Plomp, 2010; van den Akker, 2010). The major reasons for choosing this approach were that not much concrete experience was available to learn from and the participating teacher also had the expectation to improve her practical skills in organizing learning activities for group collaboration. These reasons aligned with the rationale of design research reported by Plomp (2010).

This study started with a preliminary research stage where the conceptual framework was formulated based on the review of relevant literature, and followed by three rounds of prototyping. The first round was conducted in a class on the topic of 'simple circuits'. The aim was to examine if the proposed strategies worked well. Data were collected through lesson observations.

Revision decisions were made after a formative evaluation at the end of this round as recommended by Nieveen (2010). The second round was conducted in one of the two classes on a different topic ('conductor and insulator'). The aim was to check if the revised strategies (e.g. for students' roles and time management) worked better. Data were collected and analyzed by following the same approach as in the first round. Minor revision decisions were made at the end of this round and the third round was carried out on the same topic but in the other class. The aim of the third round was to verify if the revised strategies (e.g. using fewer materials and using a revised worksheet) worked more effectively. In the end, a survey was administered with the students in the two classes to investigate their experiences and perceptions on group collaboration.

The structure of the chapter is as follows. The conceptual framework for this design research is presented in the following section. This is followed by a detailed description of the three rounds of the design research process. Each round presents the lesson design ideas, implementation and findings, and revision decisions for the next round of design. The yield of the study and lessons learned from this project are presented at the end of the chapter.

## **2. Development of a conceptual framework: The spiral problem solving process**

According to Hokanson and Hooper (2004), instructional methods can be categorized into five levels: reception, application, extension, generation, and challenge. They begin with the simplest (reception) and most common forms of instruction and extend to what is described as the best experiences (challenge). On the reception level, students are often considered information receivers; on the application level, students need to answer some questions and/or summarize information; on the extension level, students are expected to solve similar problems after learning how to solve simple ones; on the generation level, they learn how to generate or create their own solutions to complex problems; while on the challenge level, they learn how to challenge others or their own learning. These five levels of instructional methods are adapted to guide the instructional design of lessons in this study. The lesson design modifies Hokanson and Hooper's stages into an IARE (Initiation-Activity-Response-Evaluation) pattern, and further applies the activity theory as a tool for guiding the design of the activity step.

Figure 1 shows the conceptual framework for the lesson design in this study. Each lesson is designed to be a spiral problem solving process, which involves problems at different challenging levels (from low to high):

1. Warm-up problems: These are usually initiated by the teacher to introduce the topic and attract students' attention.
2. Basic problems: Students are required to solve some basic problems in groups guided by the teacher.
3. Analogous problems: Students are further required to solve some similar problems in groups by collaborating with their peers.
4. Extended problems: Students are encouraged to think and solve some in-depth authentic problems in real life scenarios.
5. Generated problems: Students are expected to present and share their findings and come up with their own problems based on their collaborative investigation. The generated problems will become the warm-up topics (or problems) of the following lesson. In this way, learning hence becomes a continuous problem solving process.

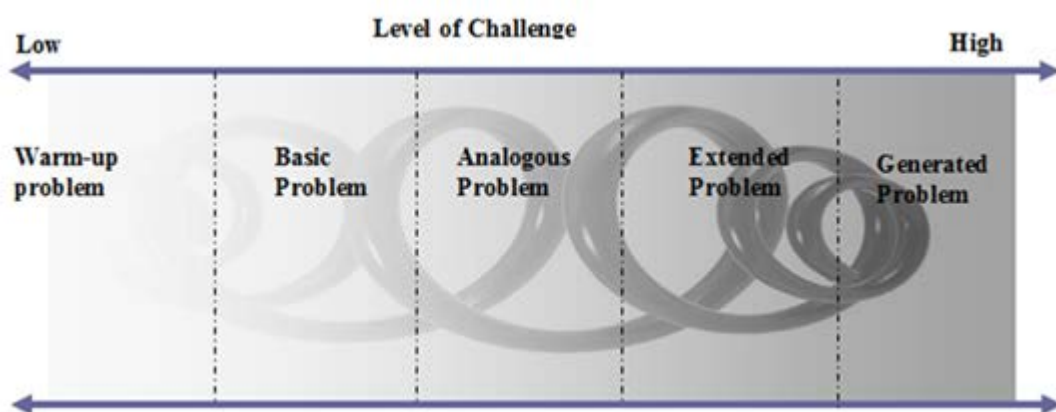


Figure 1: Spiral Problem Solving Process (adapted from Hokanson and Hooper, 2004)

Each of the abovementioned problems is gradually carried out in different stages (IARE: Initiation-Activity-Response-Evaluation) as shown in Figure 2. In the initiation stage, the teacher usually introduces the aims and schedule of the lesson. During the activity stage, students are to solve corresponding problems (e.g. warm-up problems, basic problems) in groups guided by the teacher. In the response stage, students respond to teacher's scaffolding questions or other students' queries. In the evaluation stage, students present their findings to the whole class, or are evaluated by completing worksheets.

In particular, when the students are engaged in their group activities to solve problems, the activity theory (Engeström, 1987) is used to guide the design of group learning activities. Among the key components of the activity theory, the subjects are students and teachers. According to Tabak and Baumgartner (2004), a teacher may play various roles in group work: as a monitor, a mentor, or a partner. However, the role of teachers in group activities is often neglected in existing research. This study will also address teacher's roles in promoting group collaboration, in addition to investigating the students' roles in group work.

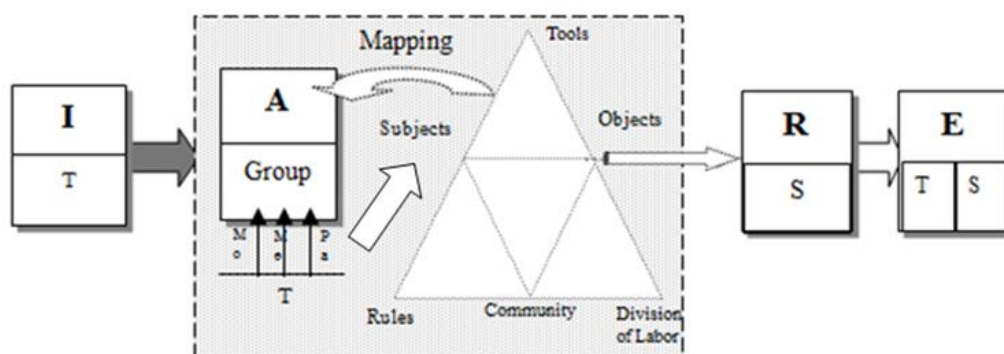


Figure 2: The IARE stages involved in each problem solving process

Tools in the activity theory can be anything used for group activities. In this study, the students' scaffolding tool they use is a worksheet, which aims to get the students focusing on the learning tasks when they are investigating.

Rules and division of labour are to ensure that the group activities can be smoothly carried out. In this study, tentative rules include: i) group members have equal opportunities to participate in investigation and voice their opinions; ii) they are given additional time to think individually before they start to collaborate; and iii) different activities may follow different rules.

The community refers to the cohesiveness of the learning group. A helpful learning community should get its members feeling that they belong to the group, in which they share the same concerns and problems, and help each other and also learn from peers (Wenger, McDermott, & Snyder, 2002).

The objects are the outcomes of the learning activity. They can be physical artefacts, observation results, or generated ideas. In this study, the objects are mainly observed results, students' perceptions and findings from the investigation.

### 3. Design/development phase

In this section, the context and the overall design of the study is firstly presented, which is followed by a specific description of each round. The strategies used for group collaboration, lesson design ideas, and findings are presented in each round. Revision decisions are suggested for further improvement in the following cycle of research.

#### Context and overall design

This study was conducted in a newly established urban primary school at Shanghai. It is a neighbourhood school with general ability students. At the time of conducting the research, the school had three grade levels of two classes each. A total number of 51 students (26 boys and 25 girls) from the two primary two classes participated in this study. The participating teacher had more than five years of teaching experience in the subject of Science. She was a devoted teacher with innovative ideas and showed great interest in participating in this project from the beginning.

The entire design phase involved three rounds of the design research process as shown in table 1.

The first round involved an identical topic in two classes, while the last two rounds were a different topic in two classes respectively. As the focus of each round was slightly different, the research question involved in each round was varied. The main instrument used for data collection in this phase was lesson observation. The following sections will describe the three rounds in detail.

Table 1: Overview of the design phase

Round	Topic (Class)	Main design activities
1	Simple circuits (Classes 2-1 & 2-2)	<ul style="list-style-type: none"> <li>• Preliminary design</li> <li>• Focusing on spiral problem solving design and activity design</li> </ul>
2	Conductor and insulator (Class 2-2)	<ul style="list-style-type: none"> <li>• Testing the revision decisions</li> <li>• Focusing on group regulations and students' roles</li> </ul>
3	Conductor and insulator (Class 2-1)	<ul style="list-style-type: none"> <li>• Validating the revision decisions</li> </ul>

## Round 1

### **Grouping strategies**

The students were not grouped based on their registration number or physical seat arrangement as usual. Rather, the students were allowed to indicate their preferred group members such as friends. Based on their indicated preference, the following rules were applied for grouping the students:

1. There were 6 groups of 3-5 members each in a class.
2. Those students who mutually indicated each other were put into a group.
3. They would have at least one friend in a group.
4. Key persons such as class leaders, or extroverted/introverted pupils were balanced during grouping.
5. The gender factor was not particularly considered.

### **Lesson design**

The topic of 'simple circuits' is actually rather complex for students in the target class. In order for students to better understand the topic, the spiral problem solving process was applied into the lesson design. Experimental materials for each group are provided in a box. The following are the problems designed for this lesson:

1. Presenting a warm-up problem: getting familiar with the experimental materials and thinking aloud their functions.
2. Solving a simple problem: Getting a bulb light on without using a switch.
3. Solving an analogous problem: getting a bulb light by adding a switch.
4. Solving an extended problem: getting a transparent touch light on.
5. Generating a problem themselves: the lesson ending up with the emergence of challenging questions or problems.

The research question was: *Do the grouping strategies and lesson design ideas work well for students to work collaboratively?*

### ***Lesson implementation and findings***

The whole lesson was implemented in the following steps. First, it started with a warm-up activity, in which the teacher showed the materials to the students, and asked them to think about how to use the materials in the following experiments (I-R-E: Initiation- Response-Evaluation). Then, the students were required to complete the three (simple, analogous, and extended) problems in groups. The teacher walked around, answering their inquiries and giving them suggestions (I-A-R-E: Initiation-Activity-Response-Evaluation). In the following step, each group was supposed to present to the whole class how they solved the problems and received feedback from the teacher and/or from the classmates (R-E: Response-Evaluation). In the end, emerging problems might be generated during group presentations and the students were expected to solve the problems in groups again (I-A-R-E2).

In general, most steps were managed to implement, but the final presentation and group investigation stages could not be fully completed due to the time limitation. But, it seems that the group presentation and sharing activity was helpful for promoting group collaboration. It was observed that when a member was presenting on behalf of the whole group, the other members often reminded him or her and gave encouragement. This was a good indicator of having cooperative team spirits, which seldom appeared in the past. Some groups came to the front to present together.

The warm-up activity attracted their attention and aroused their interest. They were eager to know what the materials were about and for what purposes. It was observed that the teacher's role was mainly as a monitor in the lesson.

### ***The emergence of challenging questions***

The teacher purposely provided an addition wire in the material box, which caused many discussions and confusions. The students came up with different ways of connection in the experiment. Some connections were incorrect, but were good for stimulating in-depth thinking. For instance, some of them were confused with the observation like:

- Why does the bulb turn off when I connect the wire to the two ends of the bulb?
- Why does the bulb light up when I turn the switch off but the bulb lights off when I turn the switch on?

These new discoveries aroused the students' interest in learning the following topic, which is about parallel circuits.

Another challenging question emerged from the activity was why the light bulb still could be on even when the two poles of a battery was reversed. A student found this problem and asked the teacher. But because there was no much time left, the teacher did not further discuss and address this problem in class.

**The use of a form for within-group evaluation and a worksheet to demonstrate their understanding**

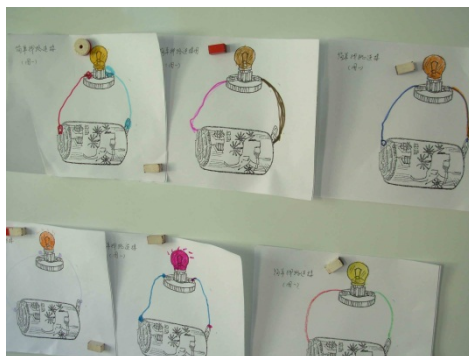
A form for within-group evaluation, as shown in Table 2, was developed. The form listed down the key activities group members needed to do and also required them to indicate the levels of collaboration when they were completing these activities. Students in groups judged the levels (high, medium, or low) of their collaboration and indicated them in the form.

Table 2: The form for within-group evaluation

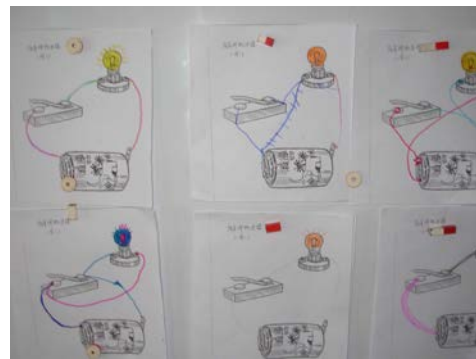
Activity	Workload distribution	Help and Support	Sharing Ideas	Caution of Safety
Wire Connection				
Switch Control				
Torch Setup				
Discovery and Reflection	1. 2. 3.			

Note: ☆: high level; Δ: medium level; ○ : Low level

The students were also required to present their understanding of circuits on a worksheet by connecting the components. Figure 3(a) shows that all groups could make simple circuits without a switch. But after a switch was added, not all groups could make correct connections. Figure 3(b) shows some common mistakes that students made and the upper middle one further shows how they corrected their connection to make it correct. The change of the wire connection reflects the students' cognitive improvement of the group.



(a)



(b)

Figure 3: Students' completion of the worksheet

**Sharing their understanding based on evidence**

During the sharing activity, all groups put their completed circuit diagrams on the whiteboard. They compared similarities and differences among the circuits and gave comments. Group 3 further shared their investigation process and why they changed the wire connection. What happened in this group was that a member directly made the same connection based on the experience of constructing a simple circuit.



But the other members disagreed with the connection and argued with him. In the end, the teacher came and suggested that they could test different connections based on their understanding. After testing, they made a correction based on the evidence from the experiment.

### ***Limitations and revision decisions***

The students were actively engaged in the group activities. In particular, the students were happy to share their group work and understanding with the whole class. However, some limitations were also found in this lesson.

Firstly, the students' roles were not clearly specified for group activities. For instance, the students were not told who should manipulate the experimental materials and set up the experiment, or who should draw the circuits on the worksheet. As a result, some group members could not cooperate well and they even quarreled with each other. It confirms that specifying clear roles is crucial for group collaboration of young kids at the primary two grade level.

Secondly, the teacher's roles needed to be further improved. In this lesson, it seemed that the effect of teacher's support for group work was not that obvious. One observation was that the time for the teacher to stay with each group was short. She could not listen to them carefully and give corresponding support needed. Rather, she used to directly tell them what was wrong or what should be corrected. The teacher's role remained as an instructor. It seemed that it might be better for her to function as a member rather than as an instructor.

Before conducting the lesson, the teacher was quite worried about classroom management. She thought that as there were so many group activities involved in the lesson, the students might be quite noisy, distracting, or hard to manage. The actual process of the lesson showed that the students were quite engaged in the group activities, and classroom management was not an issue.

Comparatively, time management was a critical problem instead. The lesson did not have enough time left for all groups to present and share their understanding with the whole class. The students were quite excited and motivated, and they all wanted to share their understanding. But the time left for their sharing was limited and many groups did not have opportunities to share with the whole class.

Another critical challenge for the teacher was how to capture and elaborate on the emerging problems generated by the students. If the teacher could keenly capture students' problems or confusions and elaborate on them immediately, it might elicit more in-depth discussions and help students construct more meaningful knowledge.

## **Round 2**

### ***Ideas for lesson design***

The lesson in the second round was about conductor and insulator. Based on the findings and revision decisions of round 1, the focus of the lesson activity design in this round was on the role of group members and the rules for collaboration. In order to give every member an equal opportunity to participate, manipulate, and share their understanding, each member was given a pen at the beginning of group activities.

The pen was not meant for writing, but presenting a chance for hands-on activities. When a student was doing hands-on activities, the other members observed, took notes, and provided necessary support. After finishing the hands-on activity, his/her pen had to be returned to the box at the center of the table, which means that his/her chance of hands-on activities was used up. Someone else who still had a pen could take over. By using this strategy, each group member had at least an equal opportunity on hands-on activities.

As the students did not have enough time to complete all lesson activities in the first round, this round only focused on one major lesson activity, which was to test the electrical conductivity of the 20 materials provided. In addition, this school has a five-minute period (called a mini-lesson in the school) before each lesson. Teachers can use this mini-lesson to introduce or extend any lesson-related materials. As some challenging questions - such as why the light bulb still can be on when the two poles of a battery are reversed - could not be addressed in the lesson of the first round, the teacher decided to discuss the challenging questions during the mini-lesson period. As the form and the worksheet worked well in the first lesson, they were kept in this round.

The research question in this round was: *Do the revised strategies (using the mini-lesson, specifying the role of group members and rules for collaboration, and focusing on one lesson activity only) work well for group collaboration?*

### **Findings of round 2**

The revised lesson design of using the mini-lesson provided a flexible opportunity for the students to complete the previous lesson activity and also for the teacher to introduce the following new topic.

The strategy of setting up ground rules and specifying the roles for members helped to implement group activities smoothly. In this lesson, the phenomenon of one member dominating group activities did not happen. No groups quarreled for getting an opportunity to investigate. Every member had the chance to do hands-on activities. They helped each other and got the experiment done smoothly.

There was still a challenge on time management. This lesson had one group activity only. However, after completing this activity, students did not have much time for sharing. It seemed that a lesson of 40 minutes had difficulties to involve problems at all levels.

In addition, a new finding from this round was that the student had developed the habit of collecting evidence by doing experiments. For instance, at the beginning of investigation, many groups were unsure if the material of foil could conduct electricity. They decided to test it out. Some parents who were invited to observe the lesson were also joining their group discussion and even told answers directly. But the children did not simply follow their advice and insisted testing it out personally. It seemed that the students had the desire to collect evidence by doing research.

### Round 3

#### ***Ideas for revising the lesson***

In order to meet the time management challenge, the lesson design was further adjusted in this round as follows:

- The number of experimental materials provided was reduced from 20 to 14. Some similar materials (e.g. plastic sheet & plastic bag; glass & glass ball) were combined and only one instance was kept.
- The worksheet was revised. In the original worksheet, two options (yes and no) were associated with each material to indicate if the material could conduct electricity. To promote further thinking, these two options were adjusted to 'prediction' and 'observation'. Students were encouraged to make a prediction before testing them out and compare if the observation was consistent with their prediction.

The research question for this round was: *Do the strategies (reducing the number of experimental materials and using the revised worksheet) help to improve group collaboration in a different class?*

The revised lesson was implemented in another class (Class 2-1). The findings are reported in the follow section.

#### ***Findings of round 3***

The group activity took less time and the whole lesson involved warm-up, investigation, and sharing. Students had enough time for presenting and sharing. The lesson observation showed that enabling students to share their understanding was crucial for them to construct correct knowledge. In addition, the students liked sharing. Every group had different observational results (although the materials were the same for each group) and wanted to share with the whole class. Also, even within a group, different members sometimes had different understanding. They were eager to share with others what they had observed.

By using the revised worksheet, new observations were further explored and discussed. Almost all groups found that foil could conduct except one group who found that only the silver side of the foil could conduct while the other side could not. This was a new observation. This group further shared how they found this 'secret': they used the metal crocodile clip to touch the foil side rather than to clip. The other groups' students were astonished and also wanted to try. As the class had about five minutes left, the teacher decided to allow them to test the two different sides of foil. As a result, the students were very excited after the additional investigation. Obviously, the sharing activity provided them with an opportunity to exchange ideas and learn from others.

#### ***Ideas for further revision***

This round also made clear that the physical arrangement of the setting also needed to be carefully considered when a lesson was designed. This lesson was conducted in a lab, which was rather spacious. When the students were sharing their findings, sometime it was hard for others to hear clearly. Also, it was quite hard for them to see clearly when they shared their drawings or diagrams on the white board. It seemed that the physical arrangement of the environment needs to be taken into account in the future.

#### **4. Assessment phase**

To further find out if the students liked the strategies for promoting group collaboration involved in the lessons, a survey was conducted on the two classes of students at the end of the 3<sup>rd</sup> round of this study. The survey questionnaire included two sections: multiple choice questions and open-ended questions. This section presents the assessment results from the survey. All students from the two classes (N=51) involved in the three rounds participated in the survey. In order for students to easily understand the questions, the teacher read out questions one by one to the students in class.

##### ***Results from multiple choice questions***

The first question was to ask students if they liked group work. 84% of them mentioned that they like working together in groups, 8% indicated that they liked individual work, and the remaining 8% did not care. This result showed that the majority of the students preferred group collaboration.

The second question was to check if they liked the current grouping strategy and the grouping result. 68% mentioned that they were happy with the grouping result and the friendship grouping strategy was better than grouping by the registration number. 20% indicated that there was no obvious difference between the current and the past grouping strategies. And the remaining 12% felt unhappy with the current grouping result as they could not get their best friends in their groups.

When they were asked what they liked in their group activities, 86% indicated they liked discussing with members, 8% hoped that their peers could listen to them, 6% did not care, and nobody took the option of solely listening to others but without speaking.

They were also asked whether they felt happy in class activities and when. 50% felt happy when they were investigating with the teacher, and 45% felt happy when they worked with their group members. However, 3% felt that they were happy when they could investigate individually and 2% students had no clear preference.

When the students were asked if they would like to have similar collaborative learning activities in other subjects, 64% of them liked this strongly, and 24% were neutral, and 12% disliked.

They were also surveyed about what they expected the teacher to do when they were doing group work. 74% indicated that they expected the teacher to work with them in their groups; 12% expected the teacher could listen to them when they were discussing; and 14% did not care. Nobody took the option that the teacher should stand on the stage and did not participate in group's discussions.

In addition, to the question about what they wanted to do after completing their group activity, students were allowed to take multiple options. 46% (N=27) indicated that they wanted to demonstrate their answers on the white board after completing group work, 22% (N=13) wanted to know the answers of other groups, 19% (N=11) hoped they could tell their answers to the teacher, and 13% (N=8) students wanted to share answers with peers.

### ***Results from open-ended questions***

An open-ended question was included to collect students' thoughts about group collaboration. Among the 51 students, 7 students did not answer and 4 other students' answers were irrelevant. The students' responses showed that the student had some concerns with the way of group collaboration and with teacher support.

There were 10 negative comments, 10 expectations, and 19 positive comments about the way of group collaboration. Most of the negative comments were about individual students 'bad behaviours'. Among the expectations, they hoped that some of their group members could be adjusted; they all had opportunities to voice opinions up in their groups; and they could share findings with other groups as well. The positive comments showed that they were happy with their group members; the experiment was interesting and they learned more from the experiment; more subjects should use the same method and other teachers should come to the lesson to observe and follow.

There were 2 negative comments, 5 expectations, and 3 positive comments on teacher's support. The negative comments were mainly about the teacher's use of voice. They felt that sometimes the teacher's voice was too loud or too soft, and sometimes she was even frightening. They commonly expected that the teacher could come to their groups more often to work with them. Positive comments included that the teacher managed to listen to them when they were sharing and the lesson was well prepared.

## **5. Yield of the project**

This section presents the *design principles* summarized from the study. Hopefully these principles can be used to guide the design of similar activities for group collaboration in other contexts.

This study shows that multiple factors affect group collaboration in a classroom setting. The factors include grouping strategies, regulations and rules, use of forms and worksheets, and roles of members. For lower primary school kids, it seems that friendship is a useful strategy for grouping. Research further shows that friendship is an effective grouping strategy as well even for university students (Ciani, et al., 2008; Wang, 2010). Setting up regulations and rules is useful for effective group collaboration to take place.

In this study, the regulations and rules included that everyone should actively participate in their group activities and their presentation must be based on evidence. The result showed that these regulations and rules enabled group members to participate actively and responsibly. In addition, the use of a worksheet enabled students to concentrate on learning tasks; the use of within-group evaluation form got them reflecting on how to improve their collaboration; and the clear roles of members allowed them to coordinate and collaborate in an effective way.

New discoveries from group activities and sharing can stimulate students' interest and motivation in conducting further investigation. Unplanned new discoveries emerged from group activities and from sharing sessions in this study. These discoveries became new challenging problems and starting points for their following investigation activities. Integrating the new discoveries into the following lesson design would stimulate and foster students' interest in subject learning and maintain their motivation in conducting further scientific investigation.

Participating in design research is an effective way for promoting practitioner's professional development.

The participating teacher reflected that her subject teaching and research abilities were greatly improved via participating in this one-year design research project. She became more confident in group collaborative learning activity design and her teaching involved more collaborative learning activities. After completing the project, she was promoted to be a leader in the field of group collaborative learning in the school. Also, she published some conference papers after participating in the project. This study confirms the claim that an “output of design research is professional development of the participants involved in the research” (Plomp, 2010, p.20).

In addition, this study indicates that the conceptual framework of the spiral problem solving process worked well in this case study. However, because of the time limitation, it was hard for the teacher and students to complete problems at all levels in a lesson. It seems that a spiral problem solving process is preferable to involve several lessons.

## **6. Reflection: Challenges and future research**

This study shows that design research has many challenges for both researchers and participating teachers. Design research tends to be a long process, which requires researchers to put many efforts. For instance, the researcher needed to collect data from various resources such as lesson observations, videos, surveys, and teacher’s reflection log in this study. It took a lot of time to analyze and summarize the data. When the interval between the two lessons in the 2<sup>nd</sup> and 3<sup>rd</sup> round was as short as two days only, the researcher had to analyze the data quickly and propose revision decisions within a short period. These required the researcher to work very hard and very closely with the teacher during that period.

The teacher had challenges in lesson design as well. Firstly, she had to reorganize the lesson content and redesign lesson activities. She could not just simply follow the existing syllabus as the new group activities were quite different from her existing teaching practice. Secondly, there was no available experience to learn from. She had to work with the researcher to come up with innovative ideas about the experiment requirement, materials used, grouping strategies, and ground rules. Thirdly, she had to learn how to capture students’ emerging discoveries and elaborate on them in time. The lesson observation shows the students’ learning interest would be greatly aroused if she could capture and elaborate on the new discoveries. All these requirements imposed great challenges on the teacher.

This study had limitations in the selection of subject content and samples. It only focused on the science subject in Primary two, and involved two classes. So the result cannot be generalized to a larger universe. However, this is consistent with the intent of educational design research, which aims to generate heuristic design principles that can provide guide and directions rather than certainties (Plomp, 2010). Future research would further explore:

- Design research in other subjects;
- Students’ roles in group collaboration;
- Teacher’s participation and support in group collaboration;
- Other grouping strategies such as grouping based on students’ ability and/or gender.

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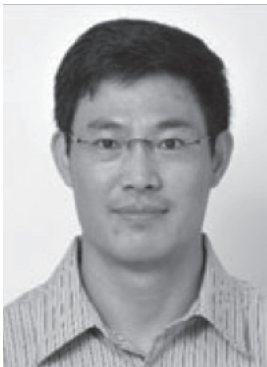
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## GO Inquire - Geological Observational Inquiry: Cycles of Design Research

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## 6. GO Inquire - Geological Observational Inquiry: Cycles of design research

Brenda Bannan

### Abstract

*The Geological Observational Inquiry (GO Inquire) system is a Web-based, customizable database driven learning program application that supports geoscience education at the upper elementary level (10-12 years old). The system was designed and developed through multiple studies and cycles of design research to support teachers and students as they engage in inquiry-based learning experiences in geosciences and specified reading strategies to promote enhanced student observation, comprehension and reasoning in and about the world around them. The cycles of design research conducted over a six-year period funded by the U.S. National Science Foundation were aimed at research-based development of an innovative intervention (e.g. a development study) as well as to develop and validate theories about learning in geoscience and understanding of the intersection of inquiry-based science and reading strategies. The system progressively evolved through multiple streams and cycles of design research over six years beginning with basic goals and features such as a more simplistic initial design criteria of guiding teachers and students in an observational, inquiry-based experience noticing natural processes. Over multiple studies comprising an in-depth formative evaluation of the system across phases, the prototype gradually improved to present a teacher-customizable system allowing for: 1) modeling and collaborative work on the geological inquiry scientific task based on a geomorphologist's mental model; 2) intersecting text resources with scientific inquiry-based observational activities investigating school grounds for signs of erosion and deposition; 3) documenting the evidence through uploaded digital photographs and visual identification of geological factors; 4) observing and questioning about important factors such as where the high and low point of the landscape are located or the composition of the soil or material is loose or compact to reason about the evidence just like a geomorphologist who attempts to understand landform change. The research questions, design criteria and corresponding evaluation cycles became progressively more sophisticated and complex across ILDF phases (see evolution represented across Tables 1 & 2 at the end of this chapter for more detail) in this design research effort and the complex, evolving journey incorporating multiple studies contributing to the generation and refinement of the system across the six years are described below.*

### 1. Educational problem

Children have difficulty perceiving that the earth changes slowly over time (Ault, 1998; Martinez, Bannan, & Kisantas, 2012). Geological observation of processes such as erosion attempts to further understanding of the evolution of landforms (Slaymaker, 1991). However, extrapolating the visual features in a landscape is an important part of geological interpretation. Geological reasoning attempts to reconstruct the most likely sequence of events that created landscape features or rock formations through retrodiction or a generated hypothesis using current information to infer how something may have happened or formed in the past. Those in the field of geoscience education or those focused on studying the more recent term of “geocognition” state that very little is known

about how students' progress toward expertise in geoscience, the necessary skills and how traditional education contributes (or does not contribute) to geocognitive development or understanding changes in the landscape (Petkovic, Libarkin, & Baker, 2009). The complexity of inquiry-based instruction in today's classroom is even more prominent when combined with the challenge of synthesizing information as is necessary in geologic study. Inquiry into geological phenomenon requires interpretation of objects with histories, and includes a high level of ambiguity (Ault, 1998). Geologists or geoscientists often reason by comparing and contrasting landforms such as mountains, valleys, and river deltas and by inferring past events from the present (Kitts, 1977). Learning to observe in a geomorphological manner is essential to being able to compare and contrast physical earth structures and is one of the core foci of this educational design research effort along with those concepts and processes articulated next.

Observational inquiry such as that occurring in the geosciences, in general, has not received the attention that more experimental forms of inquiry in science education have been given and there seems to be little understanding of how to support students in scientific observation in the classroom (Smith & Reiser, 2005; Tomkins & Tunnicliffe, 2001). However, what does seem to be critical for both experts and students is experience out in the field or natural setting and visualization abilities thought to be critical to solving geological problems (Anderson, 2002).

The role of reading in science has recently generated significant focus in the literature (Yore, 2012; Saul, 2004). Furthermore, the overt integration of reading and science is critical because comprehension and inquiry efforts in the classroom are interdependent and have common goals and strategies (Cervetti, Barber, Dorph, Pearson, & Goldsmith, 2012). Questioning and self-monitoring are two examples of these strategies (Palincsar and Brown, 1984) which improve comprehension of informational texts and are crucial for science achievement (Yore, 2004). Integrated literacy instruction across domains such as science has been stated to provide more authentic, more meaningful and efficient instruction based on the premise that knowledge construction as an integrative process (Gavelek, Raphael, Biondo, & Wang, 2000).

This design research study focused on intersecting geological observational inquiry and reading in science to support student's geological reasoning about the world around them. The multi-cycle, six year effort uncovered valuable information about student learning in this relatively unexplored area as well as teachers' understanding of inquiry-based learning and produced an effective technology learning system. The justification of the employment of design research and the methods/processes followed in this case are detailed below.

Educational design research was selected as the appropriate methodology because geoscience learning is a complex, relatively unexplored area with little understanding or theoretical ideas about how learning occurs. Kelly (2009) states that these situations warrant the use of design research methods. This study utilized the Integrative Learning Design Framework (ILDF) as a basis for the four phases of design research (see Figure 1) conducted with varying applied and empirical methods incorporated in each phase (see Bannan-Ritland, 2003; Bannan, 2009; Bannan, 2012). Bannan (2009) provides a full description of the multi-study, multi-method *programmatic* approach of design research as distinct from a single study (see Bannan chapter in volume A). It is important to distinguish that this report incorporates *multiple streams of research*, therefore includes a high level view of cycles of research that are connected which impacts the chain of reasoning articulated as *distinct from a single research focus*.

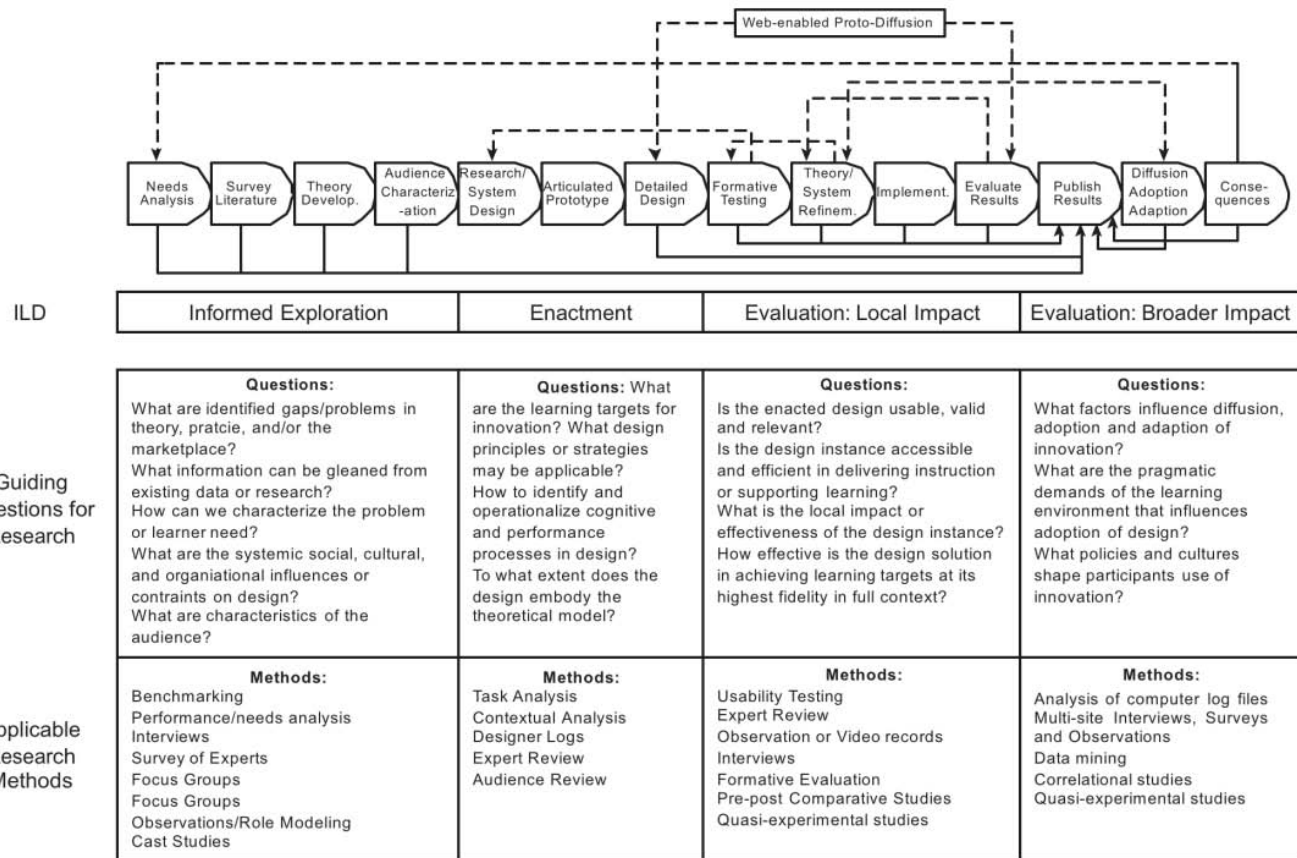


Figure 1: Integrative Learning Design Framework (ILDF)

## **2. Informed exploration phase**

The purpose of the informed exploration phase of the ILDF is to identify, describe and analyze the state of the problem or phenomenon in order to generate theoretical perspectives about how people learn and perform and corresponding design directions.

The outcomes of this phase is to locate the problem in context, review the literature and characterize audience and stakeholder perspectives to identify relevant knowledge domains and integrate applied practice, theory and research perspectives to work toward the generation of initial models or conceptual frameworks for enactment in the next phase.

### **Needs analysis**

Our research team, which was comprised of the project investigator, three graduate research doctoral students and six teacher-practitioners, initially conducted a needs analysis to determine and articulate the area of need and performance in a problem finding or design problem framing process. The needs analysis helps to initially determine what is in and out of the scope of the instructional problem and tries to determine process and input to achieve the educational goals. Rossett (1999) refers to the needs analysis process as defining the limits of the problem or domain and then determining what to do to work toward the goal of a data-driven rationale and broad description of a potential technology system.

Our approach in the initial Informed Exploration phase of the sequence of GO Inquire design research cycles was to attempt to gather and integrate information from research, theory and applied practice. The intersection of these sources provides a more comprehensive approach to frame the problem distinct from initial stages of the traditional research process which is typically limited only to a literature review. In this direction, we chose to examine the cognitive and applied literature related to science inquiry, geoscience learning and the integration of reading and science to attempt to frame the problem and then progressively narrow the research focus as well as gather input on teachers' practical knowledge and input on the educational problem from subject matter experts.

We initially interviewed representatives from the American Association for the Advancement of Science (AAAS) who directed us toward the field of geoscience given the dearth of digital teaching materials in this area. This began our journey toward introducing and supporting geological and observational inquiry processes for upper elementary students but our goals were initially fairly vague. It was clear we needed more information on children's learning related to geoscience. We then identified a geomorphologist or scientist who joined our research team whose research focus was landform change who could help guide us in the ecological validity of the science activities we might include in the system design. He reconfirmed the need for geoscience curriculum materials in the schools to support teachers in teaching this complex subject area. Next, we investigated the literature to round out our understanding of these important areas of focus.

### **Literature review**

The GO Inquire research team conducted a recursive literature review to determine what was known about how children understand geologic processes and landform change over the course of the six-year study. Initially, very few academic journal articles were identified that addressed understanding of geological processes by children and those that did were fairly dated such as Ault

(1998). The overall outcome from this review was that there is dearth of literature on geoscience learning, reasoning and inquiry which constitute a complex process typically not directly addressed in schools in the U.S. In our reviews of the literature, we began to iteratively narrow down our areas of focus related to the geologic processes that we wanted to address in the design research study cycles. Only two studies were found to directly addressed erosion and weathering (Dove, 1997; Russell, Bell, Longden, & McGuigan, 1993). The term erosion is a complex construct to understand in earth science because it is concerned with the lowering of the land surface and involves processes which operate over a long time period. A recent geoscience research review (Cheek, 2010) revealed that students have difficulty understanding a sense of scale when something is outside their ability to observe it directly and occur at very slow rates and require longer periods of time, such as the process of erosion. We attempted to intersect these findings with our direct experience with stakeholders such as teachers, students and a geomorphologist in the investigative cycles described below.

### **Qualitative observation of target setting**

In the initial stages and qualitative cycles of GO Inquire design research, we went into five upper elementary (5<sup>th</sup> grade) classrooms and one middle school (6<sup>th</sup> grade) classroom to observe and videotape their science teaching across a 6-week science unit to further understand the educational problem in context. Our research questions at this point were focused on uncovering teachers' implementation of inquiry-based science and if and how teachers connected reading and science activities in order to design a system that would take teachers' practice into account. The data from this analysis revealed significant variation in the implementation of inquiry-based science teaching and use of literacy activities in science. We found the teachers understanding and implementation of inquiry as well as their intersection of science and reading processes were limited across 5 of the 6 classrooms. The middle school teacher had the most robust interpretation of inquiry and was the most innovative in how she intersected science and reading in identifying and defining science vocabulary words, creating an important linkage between this vocabulary and the inquiry-based science lab activities. The emphasis she placed on student-generated questioning and attention to scientific vocabulary in the course of inquiry-based experiences derived from our analysis of data from her classroom were later incorporated into the GO Inquire system prototype. The classroom observational data with these six teachers was complemented by teacher interview data analysis described below.

### **Interviews of teachers**

We also interviewed these upper elementary/middle school teachers about their perspectives on their understanding of the integration of scientific inquiry and literacy activities. Results of a qualitative micro-ethnographic analysis of two of the extreme cases (classroom observations and teacher interviews) revealed that the teachers' beliefs about inquiry science teaching may influence their use of integrated literacy activities in the classroom (Bannan-Ritland, Han, Baek, & Peters, 2005). The interviews revealed tensions or dilemmas in how teachers viewed and implemented inquiry-based activities with the majority viewing inquiry primarily as "hands-on" activities. The interview data triangulated by the above described classroom observations presented a limited view and implementation of inquiry-based activities by the majority of teachers observed when compared to the definition of scientific inquiry articulated by The U.S. National Science Council in the National Science Education Standards (1996). The data analysis also revealed little evidence of the

integration of literacy activities in science teaching across the five classrooms. The studies revealed a lack of full understanding of inquiry-based science by the teachers and little evidence of combining this form of teaching with literacy activities and student-generated questioning in science during the six-week classroom observation period. The gaps in the teachers' knowledge and practice identified from these micro-cycles of investigation helped to form the initial design criteria for our system design which encompassed: 1) guiding teacher-student observational inquiry in geosciences; 2) integrating science-literacy inquiry processes; 3) prompting students to notice natural geological processes; and 4) prompting student generated, open-ended questions and 5) allowing teachers to customize the inquiry experience (see Table 1, end of the chapter).

### **Audience characterization**

Based on the classroom observations and interview data, the GO Inquire design research team was able to uncover our target audience and stakeholder's (e.g. teachers, students and subject matter experts) perspectives on inquiry teaching, geocognition and the intersection of science and literacy activities. Characterizing the target audience members for purposes of design involves getting as close as possible to observing and interacting with the teachers, students and scientists to build knowledge about the setting, context and learners to begin to construct a theoretical model for teaching and learning that provided the foundation for the system design as articulated in the educational problem section and initial design criteria described above.

In order to improve our understanding about inquiry-based teaching, one member of our design research team conducted a round of qualitative research with six fourth grade teachers to investigate the following research questions in the Informed Exploration phase about teacher's perceptions of the process of scientific inquiry:

- What are teacher perceptions of inquiry at the beginning and mid-point of a graduate course involving intensive exploration of science inquiry?
- What are teacher perceptions about how inquiry happens in a 4<sup>th</sup> grade science classroom?
- How do teachers' perceptions of inquiry compare with their perceptions of how inquiry happens in the classroom?
- How do teacher conceptions of inquiry compare with the researcher's initial and refined models of inquiry?

Peters (2005) interviewed and surveyed five volunteer teacher-practitioners whose classrooms were observed above and reviewed interview data, survey data, concept maps of the teachers' conceptual frameworks as they analyzed student work assessment. Results indicated that in regard to inquiry-based science teaching: 1) the teachers felt asking students open-ended questions was important and reported that open-ended questions were prevalent in their classes; 2) teachers did not feel strongly that evidence should be supplied to support claims by students; and 3) teachers reported a low importance for student designed scientific activities to test ideas. These ideas were subsequently incorporated into the GO Inquire system.

Additionally, teachers who were part of the design research team participated in a year long experience participating in the investigation of this educational problem also offering practical knowledge that contributed to our emerging ideas about how to address the complex goal of geological scientific inquiry (Bannan & Baek, 2008). One particular teacher involved in this



experience articulated how difficult it was for her to get the children in her urban classroom “to see” nature or to get out in their environment to examine how the earth changes slowly. Based on her insights and integrated with what we learned from all of the investigative cycles described above, the design research team arrived at goal of attempting to promote geological observational inquiry in our design efforts in order to help kids “see” naturalistic processes of geological change that occur around them like erosion and deposition of materials. In this manner, we would attempt to support in observing the world around them and learning how the earth changes slowly. This goal also aligned with a benchmark of science learning relating to understanding change processes of the earth advocated by the American Association for the Advancement of Science (Project 2061).

### **Theory development**

From the integration of the above micro cycles of investigation and data analyses in the Informed Exploration phase, the design research team was able to begin to articulate initial theoretical notions of how children may understand how the earth changes slowly and how teachers understand science inquiry and integrating it with literacy activities. At this stage, we were able to piece together these partial understandings resulting from the literature review, qualitative research cycles with kids and teachers, and experiences in the classrooms to attempt to form a more cohesive picture of the educational problem and context to then articulate clear learning goals and overarching research questions allowing them to emerge from earlier investigative cycles. In design research, this is often stated as tentative theoretical conjectures (Confrey & Lachance, 2000) about how learning might occur in this context. Integrating all of what we learned in the informed exploration phase, we articulated at this our theoretical conjecture as the following:

Intersecting scientific inquiry-based teaching with reading comprehension inquiry processes in geological observational activities may begin to promote children’s attention to, learning about and reasoning related to processes of slow landform changes on the earth such as erosion and deposition (e.g. geological reasoning).

In the next phase of enactment in the ILDF, we determined that an open-ended, customizable Web-based system that could scaffold the process of inquiry for both teachers and students could prompt visualization, comprehension and scientific reasoning processes that comprised our educational aim. We began to iteratively design and develop this Web-based system through multiple studies and cycles that would carry out (in progressively more detail through multiple prototypes), to support and elaborate the above theory. What we learned in the iterative mini-cycles of investigation in this Informed Exploration phase funneled directly into our insights into design and subsequent research as described below.

### **3. Design/development/enactment phase**

In the Enactment Phase of the GO Inquire design research project, researchers attempt to integrate and operationalize what is learned to that point into a targeted intervention or design concept to address a particular educational need or problem. Before launching into the design of a Web-based system to support our stated theoretical conjecture, the learning goals or purpose/function of the intervention or system need to be articulated. The design research team comprised of a professor, four graduate students, six teacher-designers and at specific times, a geomorphologist, who assisted us in more fully understand processes that relate to how the earth changes and how a

scientist conducts observational geological inquiry to determine our learning goals. Therefore, participatory design techniques were employed to articulate the learning goals more clearly based on our initial conjectures about learning in this context.

### **Participatory design**

Participatory design techniques are implemented by software development teams to improve design fidelity and involve directly interacting with representatives from the target audience in the design process. We view this as an applied design research method as it can be highly useful to uncover insights about the educational context, learning content as well as misconceptions and misunderstandings about the learning focus by participant audience members. In our case, the teachers on our team who were five volunteer elementary school teachers and one middle school teacher with interests in creating an inquiry-based science technology intervention as part of a year-long study in educational technology that provided them with a significant amount of graduate credits for their work on this project. The teachers served as participatory designers as they understood the context of the classroom to determine what would work best. However, the entire design research team needed to better understand our selected focus of geological change processes of erosion and deposition in order to design a detailed Web-based system that would promote teachers and students observational inquiry and learning about landform change. In the participatory design experience, the geomorphologist took the research team to a nature center near a local school and began to show us how he conducted geological observational inquiry. Standing in the naturalistic setting, he showed us geological maps of the area and began to look for the high point in the landscape which was a ridge of land near the school (see Photo 1).



*Photo 1: Geomorphologist showing how he conducts geological observational inquiry*

Then, the geomorphologist looked for the low point in the landscape which was a nearby stream in the nature center. We followed him walking down to the stream where he began to examine the rocks and materials in the stream to determine if the material was loose or intact as well as other features of the material. As he conducted this inquiry, the geomorphologist explained to us that he attempts to retrodictively (e.g. retrodiction, as opposed to prediction is defined as utilizing present information or ideas to infer or explain a past geological event) understand how the landscape may have formed based on what he can observe now and infer processes such how and where water might have flowed from the high point of the ridge to the low point of the stream. He then attempts to

use the information he gathers to reason about what may have happened geologically in that area. One of his conclusions in our inquiry process and visual reading of the landscape was that water coming down from the ridge began to erode the stream bed and shaped the landscape slowly over time and the type geological material in the area and the stream (e.g. loose, compact, hard, soft, etc.) informed his reasoning.

From this participatory design experience and later direct instruction about erosion processes and how they impact landform change, the design team was able to attempt to distill the geomorphologists' mental model into an accessible observational inquiry process for kids. In fact, one of the teachers on the team later took her children into the nature center and modeled the geomorphologist's process conducted with the design team with the children in her classroom providing some evidence that this technique (e.g. looking for the high point in the landscape, looking for the low point, examining the material and geologically reasoning about what erosion and deposition might have occurred in the area) could be taught to kids.

At this point, with our informed exploration of the educational context, some theoretical notions on how learning may or may not occur in observational inquiry/geoscience reasoning and practical experience of teachers interacting directly with a geoscientist, we felt we were ready to begin to conceptually design an initial prototype of the Web-based system to support these potential learning processes. Through several iterations of the GO Inquire system, we attempted to articulate or embed our emergent theoretical model or criteria (see Table 1) that reflected state-of-the-art knowledge and analysis in the design of the learning system to allow for cycles of feedback and iterative revisions of the model and corresponding design.

The emergent prototypes or "half-products" (as referred to by other researchers in this volume) resulted in a progression of our ideas about learning in this area reflected by our key characteristics or design principles as well as changes in the GO Inquire system indicated by features (see Table 1). The process and the methodologies we employed (both basic and applied research methodologies) are further described below beginning with articulating clear learning targets and associated research questions (see Table 2).

### **Learning targets/research questions**

One of the most difficult points in design research is to articulate a single or several learning targets to provide focus for designing an intervention in a complex educational setting. The GO Inquire context was no less complex than other design research efforts but over time and through guidance from the ILDF, we progressively worked toward clarity in our stated learning targets reflecting key characteristics and corresponding research questions that supported our targeted learning design (see Tables 1 & 2, end of chapter). This process was by no means linear as it was, in fact, messy, iterative, and round about at times but resulted in the following initial articulated learning targets or criteria established for the system:

Students using the GO Inquire system will:

1. Engage in geological observational inquiry by asking questions and noticing geomorphological features in their world :
  - Use observational skills, photographic analysis, compare and contrast landform features.
  - Intersect their prior knowledge and experiences, ask questions, combine their readings about geological phenomena with observations to promote geological reasoning.
2. Define geological terms for collaborative inquiry.
3. Identify and describe geomorphological processes :
  - Focus on visually identifying/describing processes - erosion, deposition, transportation in the landscape.
  - Cue and share identification of geological features as modeled by geomorphologists (e.g. high/low point of landscape, steep/shallow topography, water velocity and path, intact/loose geological material, etc.).
  - Use observation through visual cueing combined with inquiry-based questioning about landform change to reason about geological phenomena.
4. Observe, read and write about geomorphological processes with peers to reason about cause and effect related to geomorphological changes such as erosion, deposition and transportation of geologic material using digital photographs.
5. Promote retrodiction (inferring how things might have been in the past):
  - Realize change in landforms and what/why these might have changed (processes such as erosion, transportation and deposition of geological material).

The above learning goals were associated with the following initial, broad research questions:

1. How do teachers and students connect and carry out observational inquiry and reading-writing processes in a structured experience about landform change?
2. How do students geologically reason when asked to identify and use retrodiction to investigate erosion processes in their local environment?

Clarifying cognitive and performance processes or tasks that support theory inherent in the design is crucial for creating and testing a theoretically-based innovation. Nieveen (2009) refers to these necessary components of design research as the key characteristics, guidelines, and implementation conditions related to the design that then collectively in use can be iterated and tested to ultimately provide a theoretical/empirical argument. Regardless of the terminology used, in the design research process, there is an important requirement to attempt to directly align research questions (based on cognitive theoretical conjectures and learning targets) with the learning technology design features/principles that are enacted in an applied experience to test theory and improve the system simultaneously. The research design then correlates closely with the system design and may co-evolve through multiple iterations.

The ILDF attempts to promote the alignment of the research design and the correlating system design features as a major step in the enactment phase. Initial statements about the GO Inquire research foci and corresponding system design features resulted in the goal of engaging upper elementary students and teachers in connecting observational inquiry and reading-writing processes that may result in improved identification and reasoning about slow landform change evidenced by erosion. The ultimate aligned system design goals that evolved over several iterations were to

design a flexible and customizable inquiry-based structured experience that allows for teachers' customization and promotes students visual recognition and geological reasoning through collaborative reading and writing about landform change (e.g. specifically erosion and related geological processes) in local contexts (see Table 1, end of chapter).

Linking cognitive theory to specific designed technology features should result in testable design principles or heuristics that assist the researcher in testing or evaluating the above research questions through embedding these design principles/heuristics in the prototype. The principles ultimately enact the theoretical conjectures operationalizing them into instructional strategies in the enactment phase. In the GO Inquire system, cognitive theories that were initially relied upon related to scientific inquiry and geological reasoning were:

#### Inquiry-based Learning

- develop students' ability to engage, explore, consolidate and assess information (Shamansky, Yore, & Good, 1991).
- highlight basic inquiry processes of observing, comparing, contrasting and hypothesizing, intersecting and communicating information.
- treat inquiry as a process that is individually constructed by each student based on his or her interaction with the physical world and abstract ideas (Keys & Bryan, 2001).

#### Geological reasoning

- address part of the AAAS Benchmark "Water shapes and reshapes the earth's land surface by eroding rock and soil in some areas and depositing them in other areas...".
- focus on slow landform change and small, steady processes involved in erosion and the relationship between erosion and related processes and landform changes.
- promote an emphasis on geomorphological science that remains fundamentally interpretive rather than experimental, focusing on observational, comparative, categorical inferences and causal interpretation (Ault, 1991).
- involve observation of natural/representative phenomena and exploration of processes to examine landform features to promote reasoning about how they were formed.

One of the most important steps in the Enactment phase is to attempt to link theory to practice through operationalizing selected cognitive theory or theoretical conjectures into instructional strategies that ultimately manifest as features of the technology learning system. Once the team had clarified the learning targets, research questions, cognitive theory and related theoretical conjectures operationalized through the aligned system/research design statement, we began to embark on the detailed design of the system to allow for evaluation and testing.

#### **Conceptual design**

In the GO Inquire system, the system and research design involved investigating how teachers and students intersect observational inquiry and reading-writing processes when engaged in geological inquiry based on current theory and practice. To articulate our initial design schema, we first derived a content, process and data elements to articulate the basic elements of the system (see Photo 2).



*Photo 2: Geomorphologist working with teacher design researchers*

Through the participatory design and formative evaluation process, this basic system began to expand and change as we conceptually designed and described the flow and process of the geological observational inquiry experience modeled on our experience in the field with the scientist and the teachers' input on what would work in the classroom. This elaborated inquiry process model or flow of learning task was elaborated into a more detailed interface design described below and expanded our understanding of how learning may occur in this context.

### **Detailed design**

The next step of the GO Inquire project enactment phase was to build the detailed design and interface that reflected our key characteristics or design principles represented as the following and aligned with corresponding visible (some not visible) features of the user interface (see Figure 3):

- guide students through a place-based, structured geological inquiry learning experience through a performance support system customizable by teachers in different languages (see Figure 2).
- enhance visual perception and analysis of geological features in their local environment to document and reason about erosion processes:
  - to visually identify, upload and “stamp” features of geological phenomenon (e.g. high/low, steep/shallow, loose/intact) (see A).
- guide students to integrate reading and writing with observational geological inquiry including:
  - explicating student prior knowledge by generating questions about their geological environment through an inquiry question bank (see B).
  - defining geological terms through reading other sources, summary writing, locating representative visuals and citing sources (see C).
  - identifying and justifying visual selection of geological features of the landscape related to erosion processes (e.g. why chose selected area as the high or low point of the landscape, etc.) (see D).
  - monitoring their own and synthesizing peers insights and reasoning about geological processes in their local landscape (see E).

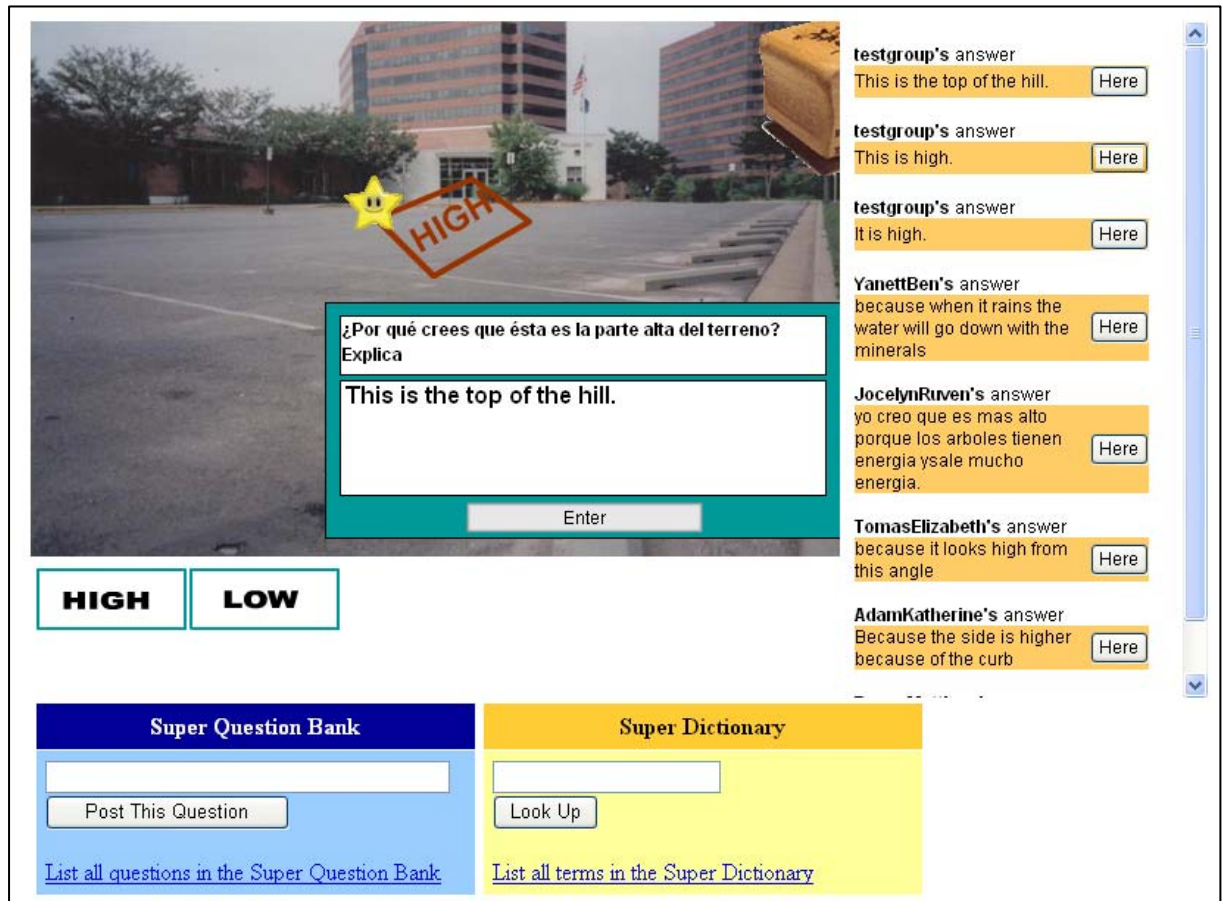


Figure 2: GO Inquire system interface

Our chain of reasoning is reflected in the embodiment and progression of these key characteristics, corresponding interface features and more complex research questions that evolved across ILDF phases as represented across the columns of Tables 1 and 2. The prototype provided enough functionality to begin to test it with elementary students in the next phase of the ILDF to begin to formatively evaluate its local impact.

#### 4. Local impact phase

Once a physical prototype exists, it allows for formative evaluation and further testing of the theory/system to inform further understanding of the enacted learning phenomenon. The GO Inquire team was able to evaluate the system as well as begin to identify what learning variables might emerge in this experience. We initially focused on usability criteria of the system and how the teachers and students carry elect to use the system. Typically, this phase involves local, iterative, small scale testing of the impact of the system in the classroom or with individual students. In the GO Inquire project, we employed multiple cycles of formative evaluation including usability testing, one-to-one, small group and field trial testing, although, we only describe the major cycle here given space demands.

### **Formative evaluation testing**

We formatively tested the GO Inquire system with a purposive sample of two teachers and 20 students in a group-based activity with an entire class in a bilingual Spanish-English elementary school in the U.S as we wanted to see if the system was customizable for use with two different languages as two of the research team members were bilingual (see Table 2, end of chapter). The two teachers were interviewed concluding the session. This evaluation cycle modeled Gillham's (2008) semi-structured observation approach "...where we are after insight into the practicalities of learning a procedure. There will be hints and clues from the successes and difficulties of those using the software; and we can ask them what they found useful or not, as the case may be, in the form of training they were given (p.33)." The 60-minute class session was videotaped and analyzed over multiple review sessions for problems and successes according to Gillham's approach and log files or raw record of what students entered in the system was also analyzed to see if students could appropriately identify visual geological features (Kuniavsky, 2003).

In the whole classroom testing, the bilingual teachers were provided a lesson plan guide in English that included prompting for student questions about geology that they translated in Spanish, then the class examined photographs uploaded by the teacher of their local playground to look for evidence of erosion for collaborative analysis in the classroom. Our formative evaluation questions and focus were related to how teachers would introduce, guide and react to the lesson plan as well as usage of the system and how students would interact and perceive the system in the teams of two or dyads as well as what information did they enter into the system. Research questions, methods and corresponding results are reported in Table 2 (end of chapter).

After several cycles of formative evaluation (the evolution of one aspect of design criteria described below), and adjustments to the system and teacher lesson plan were implemented (see local impact and broad impact column of Table 1 (end of chapter) for other progressive changes in key characteristics and features). Based on the successful implementation, our theoretical conjectures about geological observational inquiry were expanded to incorporate collaborative, dyad interaction and students building on other students input to promote higher level reasoning about geological phenomena. As an example, one outcome and revision of the formative evaluation cycle highlighted the excitement expressed by the students in seeing each other's comments resulted in an improvement or addition of a system feature to display where the student who made the comment had placed their stamp as well as adding a feature allowing students to cut and paste important ideas/words from other's comments intersected with their own to write a summary of the discussion. This promoted the progressive evolution of one key design criteria to include monitoring, clarifying, and synthesizing peer's reasoning (not just their own) further connecting scientific inquiry and reading which could be viewed as similar to scientists reviewing, summarizing and integrating colleagues work and observations with their own. The next broad impact phase of the ILDF permitted these and lesson plan changes to progressively embark upon broader and more rigorous testing of the system through applied and empirical research.

### **5. Broad impact/assessment phase**

The purpose of the broad impact or assessment phase of the ILDF is to further test the theory and system through cycles of qualitative and/or quantitative research. The GO Inquire project at this phase included a broader audience sampling, qualitative as well as mixed method study cycles. Due to space limitations of this chapter, the reader is referred to reporting of the actual cited studies for



extensive detail however, the main questions, methods and results are reported in Table 2 (end of chapter) of a portion of the studies conducted during the six-year cycle. The outcomes of this phase include an improved understanding of the contextual factors that may influence learning while using the system as well as enhanced conceptualization of the key variables in intersecting literacy processes with learning in geological observational inquiry. A progressive scaling up process of testing of larger and larger groups would also be appropriate for this phase that may include a multi-method, multi-site confirmatory study sequence, however only the outcomes of four empirical study cycles are reported here that were carried out in a single dissertation study (Martinez, 2008).

### **Mixed method quasi-experimental study**

Martinez (2008) conducted a study using the GO Inquire system implementing an instructional model (called INSCIREAD) that intersects overt cognitive strategies used in both scientific inquiry and reading comprehension in an inquiry-based instruction experience using GO Inquire. The study involved 57 fourth grade students including eight with a range of emotional and learning disabilities. The intervention involved a six-day sequence of activities involving use of the GO Inquire system and explicit instruction in inquiry-based scientific text content and comprehension-fostering cognitive strategies that may overlap in reading and science (e.g. self-monitoring-asking questions, clarifying understanding, selecting important information, synthesizing and questioning).

In this study, the dependent variable comprised a text recall protocol under baseline conditions with no intervention and the independent variable was exposure to the intervention of the instructional model INSCIREAD that included exposure to the GO Inquire system. The groups all read 15 daily texts and each group progressively advanced from baseline conditions to intervention. Results indicated that the first group without disabilities (N=17) improved their mean scores of daily text recalls by 55.20% from baseline, the second group without disabilities (N=14) improved their scores by 3.3% and the third group without disabilities (N=18) by 4.13%. For those students with disabilities, the first group (N=4) improved their mean scores by 26.32% compared to baseline and the second group by 24.50% demonstrating some documented evidence that the GO Inquire system and INSCIREAD approach improves scientific text recall.

This study also examined science text recall or the ability to comprehend written science text related to slow landform changes by water after using the system as well as determined level of generated questions and misconceptions as well as student awareness of the relationship between science and reading. Results showed that some change but not statistically significant change in text recall between the treatment and control groups of students without disabilities. However, a higher level of questions were generated from pre to post test in the treatment group that was statistically significant among students without disabilities compared to the control group. The content of some of the student misconceptions analyzed proved very interesting as summarized below for example students demonstrated the following misconceptions or misunderstandings revealed by working in GO Inquire:

- The path the river follows was there before there was water.
- Processes of accumulation rather than erosion contributed to the formation of the Grand Canyon.
- Catastrophic and magical reasoning about landform change.
- Erosion as a completed rather than ongoing process.
- Unless it was raining, erosion did not take place.

All students understood that water moves from high to low based on gravity but some students confounded information from other science topics with erosion including concepts about the water cycle, rock cycle, water pressure, and plate tectonics. These insights into student misconceptions and conceptual confounding provided an important basis for further revisions of the system and implementation plan.

## 6. Theoretical yield of GO Inquire design research study

The theoretical yield of the multi-year, multi-method GO Inquire design research effort included insights such as:

- Teachers and students can successfully connect and carry-out observational inquiry in geosciences with an improved awareness of the connection between science and reading. Working mechanism: scaffolded observational inquiry process combined with overt instruction in reading/science inquiry strategies.
- After engaging with the GO Inquire system and lesson, students produced higher level questioning, targeted visual identification of geological landform change, and collaborative geological reasoning. Working mechanism: directed student-generated questioning, capture and analyze photographic evidence of erosion and explicate reasoning how erosion may have happened based on landform elements.
- Students can be prompted to visually identify geological landform change in their environment, demonstrate a reduced number of misconceptions about geological processes and improve their scientific text recall after using the GO Inquire system. Working mechanism: collaborative, focused observational inquiry in local context and synthesis of reasoning through reading and writing in Wiki-like interface.
- Teachers vary in their understanding of inquiry-based teaching often with definitions that are primarily interpreted and limited to “hands-on” learning in science. Working mechanism: scaffolded, customizable, geological inquiry process embedded in Web-based interface.
- Upper elementary students are motivated to participate in collaborative observational geological inquiry particularly in their local school environment, working mechanism: ability to see peer comments/visual identification and reasoning about familiar landscape induced excitement and motivation in using the GO Inquire system.
- Students can visually identify instances of erosion in their environment and begin to reason retrodictively about geological processes such as erosion, deposition and transportation when cued to do so in a structured experience. Working mechanism: breaking down the visual retrodictive reasoning about erosion processes (e.g. high/low, steep/shallow, etc.) based on an accessible process modeled by a geomorphologist.
- Students can individually and collaboratively articulate geological reasoning about erosion processes and landform change while intersecting their own ideas with their readings and with their peers. Working mechanism: employing reading/writing to generate scientific questions and definitions as well as synthesis of geological reasoning in a collaborative environment.
- Students connect cognitive reading strategies and learning science in observational inquiry through posing questions, self-monitoring, clarifying understanding and selecting important information in the INSCIREAD teaching approach. Working mechanism: overtly teaching questioning and self-monitoring in an observational geological inquiry experience can connect reading and science for students.

- Upper elementary students confronted misconceptions about geological concepts based on confusion of processes, other scientific phenomenon recently taught and incorrect understanding of terms. Working mechanism: collaborative use of the GO Inquire system and integrated teaching and use of reading/writing strategies in an observational inquiry experience can reduce misconceptions.

## 7. Conclusion

The GO Inquire case of design research provides an example of a multi-phase, multi-method investigation involving applied and empirical cycles of research that yielded multiple insights across teacher, student and researcher understanding and practice of supporting geoscience education and intersecting reading and science. It is hoped that this study will provide some guidance for design research investigations based on the ILDF for other researchers embarking on similar complex, intense investigations.

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Table 1: Key characteristics/design criteria and features of GO Inquire added by progression through four phases

	Informed Exploration (IE) (Year 1)	Enactment-Detailed Design (DD) (Year 2-3)	Local Impact (LI) (Year 3-4)	Broad Impact (BI) (Year 5-6)
<p><b>Key characteristics/design criteria</b> (progression, gradual improvement and refinement/ specification of design based on research outcomes across phases/ columns)</p>	<ul style="list-style-type: none"> <li>• <b>Guide teacher-student observational inquiry in geosciences</b> (associated with Table 2: IE Phase #1,3,6 research results)</li> <li>• <b>Integrate science-literacy inquiry processes</b> (associated with Table 2: IE Phase #4) research results)</li> <li>• <b>Prompt students to notice natural geological processes</b> (associated with Table 2: IE Phase #2 research results)</li> <li>• <b>Prompt student generated, open-ended questions</b> (associated with Table 2: IE Phase #4,5,6 research results)</li> <li>• <b>Reduce misconceptions in geosciences</b> (associated with Table 2: IE Phase #2 research results)</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Guide students to analyze landscape for evidence of erosion in place-based inquiry experience</b> (associated with Table 2: DD Phase #1 research results)</li> <li>• <b>Provide accessible model of visually identifying examples of erosion processes, landscape features and qualities of materials</b> (associated with Table 2: DD Phase #2 research results)</li> <li>• <b>Prompt students to connect reading and science inquiry through activities such as to define terms, generate questions, describe erosion processes through reading, synthesizing and writing about erosion processes</b> (associated with Table 2: DD Phase #1,2 research results)</li> <li>• <b>Prompt students to articulate their reasoning about erosion processes</b> (associated with Table 2: DD Phase #2 research results)</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Prompt students to review their peer’s responses to visually compare and consider or reconsider their own reasoning about erosion processes similar to scientist’s reviewing each other’s chain of reasoning</b> (associated with Table 2: LI Phase #1, 2,3,4 research results)</li> <li>• <b>Parallel use of cognitive strategies in inquiry-based science and reading comprehension of scientific text</b> (associated with Table 2: LI Phase #5, 6 research results)</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Explicitly teach strategies of questioning and self-monitoring in both science and reading incorporated with use of the GO Inquire system to increase science text recall, combat misconceptions and promote awareness of parallel inquiry strategies in reading and science</b> (associated with Table 2: BI Phase #1a-d research results)</li> <li>• <b>Promote student generation of questions, search for answers to questions in scientific text, monitor understanding, clarify, synthesize, review peer’s answers and self-monitor reading and reasoning.</b> (associated with Table 2: BI Phase #1c research results)</li> <li>• <b>Promote collective rather than individual meaning of text</b>(associated with Table 2: BI Phase #1d research results)</li> </ul>

Table 1: Key characteristics/design criteria and features of GO Inquire added by progression through four phases (continued)

	Informed Exploration (IE) (Year 1)	Enactment-Detailed Design (DD) (Year 2-3)	Local Impact (LI) (Year 3-4)	Broad Impact (BI) (Year 5-6)
	<ul style="list-style-type: none"> <li>• <b>Allow teachers to customize an accessible, inquiry experience for students</b> (associated with Table 2: IE Phase #1,3,7 research results)</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Create Spanish and English prompts for use in bilingual school settings</b> (associated with Table 2: DD Phase #3 research results)</li> </ul>		<ul style="list-style-type: none"> <li>• <b>Promote awareness of parallel inquiry strategies in science and reading comprehension</b> (associated with Table 2: BI Phase #1 research results)</li> </ul>
<p><b>Specific features of GO Inquire system</b> Implementing key characteristics/design criteria stated above</p>	<p>Web-based performance support system to walk teachers and students through structured observational inquiry experience related to geoscience</p>	<ul style="list-style-type: none"> <li>• Identify and digitally photograph evidence of erosion in local context or playground</li> <li>• Upload digital evidence of erosion into GO Inquire system</li> <li>• Visually identify geological features (e.g. high point and low point, loose or intact materials) of the landscape in the digital photograph with digital stamps</li> <li>• In English or in Spanish, write definitions of geological terms with readings outside system, and/or contribute photographs representing terms</li> <li>• See peer's responses to all features described above in a Wiki-like interface</li> </ul>	<ul style="list-style-type: none"> <li>• After identifying and reasoning about erosion processes, view peers' visual stamps and reasoning to more deeply consider or reconsider their own reasoning</li> <li>• Added Super Dictionary</li> <li>• Added Super question Bank</li> <li>• Added Synthesis Page</li> <li>• Added view of peer's comments with placement of stamps</li> <li>• Teacher modification of photographs, sequence of pictures, stamps and synthesis</li> </ul>	<ul style="list-style-type: none"> <li>• Created a 6-day instructional model an plan (INSCIREAD) incorporating GO Inquire system addressing the intersection between inquiry-based science and reading comprehension in teaching geosciences content about erosion processes</li> <li>• Named self-monitoring and questioning strategies for students view</li> </ul>



Table 2: Overall research questions, methods and results by phase

	<b>Informed Exploration (IE)</b>	<b>Enactment-Detailed Design (DD)</b>	<b>Local Impact (LI)</b>	<b>Broad Impact (BI)</b>
Overall research questions by phase	What is the area of need or state of the problem in intersecting science and reading processes in geoscience inquiry-based instruction?	What would a technology-based system guiding teachers and students through an inquiry-based experience connecting science and literacy related to noticing erosion processes include?	How do teachers and students use and perceive the GO Inquire system? <ul style="list-style-type: none"> <li>How do they connect and carry out observational inquiry and reading-writing processes in a structured experience about landform change?</li> <li>How do students geologically reason when asked to identify and use retrodiction to investigate erosion processes in their local environment?</li> </ul>	(Martinez, 2008) 1a. Does the use of GO Inquire and explicit instruction of scientific text content and comprehension strategies of questioning and self-monitoring in the INSCIREAD instructional experience have an effect on <b>science text recall</b> or; 1b. <b>awareness of interdependence of science and reading</b> ; 1c. level of <b>generated questions</b> ; and 1d. <b>number of scientific misconceptions</b> ?
Methods/study cycles	<ol style="list-style-type: none"> <li>Needs analysis</li> <li>Literature review</li> <li>Expert interviews</li> <li>Classroom observations</li> <li>Teacher Interviews</li> <li>Teacher survey/concept maps</li> <li>Characterize audience</li> </ol>	<ol style="list-style-type: none"> <li>Participatory design</li> <li>Identify learning targets</li> <li>Operationalize learning targets in detailed design</li> </ol>	Formative evaluation: usability of lesson integrated with system, classroom observation, log file analysis and teacher interviews in diverse, bilingual school setting (2 teachers, 20 students)	1a. Single subject multiple baseline across groups (57 fourth-grade bilingual students – 8 with special needs) 1b. Qualitative interviews (13 students randomly selected from the 57 students described above) 1c. Single subject multiple baseline across groups

	Informed Exploration (IE)	Enactment-Detailed Design (DD)	Local Impact (LI)	Broad Impact (BI)
				(57 fourth-grade bilingual students) 1d. Semi-quantitative analysis of number of scientific misconceptions (49 fourth grade bilingual students)
Results	<ol style="list-style-type: none"> <li>1. Lack of teaching materials in geosciences</li> <li>2. Little understanding of how children understand geologic processes like erosion.</li> <li>3. Teachers and children need support in this area</li> <li>4. Teacher understanding of inquiry and intersecting science -reading limited</li> <li>5. Inquiry perceived as “hands-on” activities primarily</li> <li>6. Teachers broader definition of inquiry after participating in design research, student open ended questions in inquiry was important</li> <li>7. Elicit teacher practical knowledge/needs</li> </ol>	<ol style="list-style-type: none"> <li>1. Observe and capture geomorphologist inquiry process of visually reading landscape and retrodictive reasoning about erosion</li> <li>2. Engage in observational geological inquiry, define geological terms, identify and describe erosion processes and features to peers, infer and reason how change occurred (retrodition)</li> <li>3. Several Teacher-designers and stakeholders offered perspectives from a bilingual school setting</li> </ol>	<ol style="list-style-type: none"> <li>1. Students in a bilingual school setting recognized imagery of their local playground</li> <li>2. Students able to visually identify geological features with stamping in dyads</li> <li>3. Teachers felt system motivated students to more closely observe and felt they spent more time on task, with significant collaboration with each other</li> <li>4. Teachers felt need to more explicitly direct attention to geological features during introduction</li> <li>5. Reading other student dyad responses provoked much interest</li> <li>6. Didn't use the question and dictionary bank extensively</li> </ol>	<ol style="list-style-type: none"> <li>1a. From baseline to treatment, students improve their mean score of text recall</li> <li>1b. Students were able to make connections related to content and strategies in both science and reading</li> <li>1c. Teaching and prompting questioning and self monitoring in an integrated science-reading inquiry experience demonstrated higher level of generated questions post intervention.</li> <li>1d. Significant reduction in number of geosciences misconceptions</li> </ol>



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## Fostering Science Comprehension, Vocabulary and Motivation in English Language Learners: A Design Research Study

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# 7. Fostering science comprehension, vocabulary and motivation in English language learners: A design research study

Ana Taboada Barber

## Abstract

*In this study we assessed the outcomes of two alternative interventions (reading comprehension and vocabulary instruction in the content area of science) on Grade 4 English Language Learners' (ELLs) reading comprehension and science vocabulary. Using an Educational Design Research (EDR) approach we explored how modifications to the Contextualized Vocabulary Instruction (CVI) and to the Intensified Vocabulary Instruction (IVI) interventions influenced quantitative findings on the effects of both interventions. Qualitative data obtained from researcher-teacher debriefs and observations guided the changes made to each intervention. These modifications, while guided by our pedagogical goal, led to stronger interventions that more explicitly gave the quantitative results on vocabulary and comprehension obtained at the end of the study. Our quantitative findings indicated that CVI had stronger benefits for students' science comprehension and student engagement, while IVI resulted in stronger short term vocabulary gains. The quantitative findings shed light on implications for literacy practices for ELLs, but more refined guidelines for these practices could be based on our qualitative results and the modifications allowed within the framework of EDR.*

## 1. Introduction to the problem

As discussed in the first part of this book, Educational Design Research (EDR) is a systematic research approach that aims to design, develop and evaluate educational interventions as solutions for complex problems in educational practice (Plomp, 2010). As a researcher in the fields of literacy and educational psychology, at the time I first approached our study using EDR in 2009 (Taboada & Rutherford, 2011), I had already considered alternative research designs for the problem and questions at hand. Specifically, my research interests include the development of effective literacy interventions for students who come to the United States as the children of immigrants and who learn to speak English while attending US schools. This population of students in the US includes individuals who come from a language background other than English (80% Spanish) and whose English proficiency is not yet developed to the point where they can profit fully from English-only instruction. As a group they are broadly denominated English-language learners (ELLs; August & Shanahan, 2006). The demographics of ELLs have grown exponentially higher (169%) than that of the general school population (12%; Francis, Rivera, Lesaux, Kieffer, & Rivera, 2006) in the USA and reports indicate that they consistently fall behind their English-speaking peers on literacy (reading and writing) indicators. For example, recent results from the National Assessment of Educational Progress (NAEP; National Center for Education Statistics, 2011) indicate that 71 % of English language learners (ELLs) and 36% of Latino Grade 8 students scored at the below-basic level in reading compared to only 15% of their White native English-speaking counterparts (National Center for Education Statistics, 2011).

It is well known that most ELLs in the US confront an educational challenge where they must study and be tested on grade-level of content based curricula in English at the same time that they are learning that language.

This is difficult for the students and for their teachers, few of whom have had specific professional development on effective approaches to students who are not proficient in the language of instruction (e.g., Francis & Vaughn, 2009). The scenario for ELL students is further complicated when they reach or enter US public school systems in the late elementary-grades or beyond, once a large number of their English native speaking peers have already developed "reading to learn skills" in the early grades. At this juncture, ELLs need to learn both the language and literacy skills necessary to succeed in English as well as the content knowledge to perform on a variety of standardized measures in content areas. Furthermore, this knowledge needs to develop successfully to allow ELLs to function productively in an increasingly specialized knowledge-based economy.

The complexities of the educational scenario for literacy development in the content areas for ELLs prompted me to embark on a research trajectory that considered multiple research designs (i.e., experimental, quasi-experimental and naturalistic/descriptive) to explore both the cognitive and motivational variables affecting ELL's literacy development as well as potential interventions to support and enhance their learning. EDR has provided my co-author and myself with a flexible, yet rigorous research methodology to tackle the complexities of developing a literacy intervention in science for Grade 4 (8-9 years old) ELL students (Taboada & Rutherford, 2011).

The principles of EDR (as discussed in Plomp & Nieveen, 2010 and in Reinking & Bradley, 2008) allowed us to approach the complex problem of late elementary ELLs' literacy in the domain of science through two innovative interventions. EDR provided a framework to compare two interventions with the goal of learning about the components that constitute the most effective practices for achieving specific literacy outcomes. Our primary pedagogical goal consisted of learning about the best combination of instructional practices to support the reading comprehension and academic (science) vocabulary of grade 4 ELLs of intermediate English proficiency. Furthermore, because motivation to read is an essential component of literacy development with ELLs, our secondary pedagogical goal was to explore students' perceptions of teacher supports for reading motivation and whether these were related to student engagement in science. These two goals were captured in the following research questions: What constitutes a sustainable set of practices to enhance the science reading comprehension and vocabulary of grade 4 ELLs? To what extent do grade 4 ELLs perceive teacher efforts to support their autonomy in reading? Do these perceptions relate to student engagement in science reading? What modifications to the intervention mostly contribute to inform our quantitative findings?

In addition to the flexibility of collecting data during the intervention and making the necessary modifications to it, EDR provided us with a framework that allowed examining nuanced components of instruction (e.g., implicit versus explicit instruction of science vocabulary) to test ingredients of a specific intervention to impact specific outcomes. To achieve the pedagogical goals we, first, embarked in a preliminary phase in which we developed two instructional approaches grounded in previous literature that focused on science content through the use of interesting texts. In line with the design of other formative experiments (e.g., Reinking & Watkins, 2000), two alternative interventions were preliminary developed in this study because we were interested in comparing the specific instructional components that could *differentially*

impact the development of academic language (i.e., reading comprehension and academic vocabulary) in ELLs. Second, in a design or development phase, we checked for essential components within each intervention.

In a third phase we implemented the two theory-driven interventions and allowed teacher adaptations and modifications to the practices proposed in the original prototypes to inform data cycles. These modifications will, we hope, contribute to the literature on literacy practices for an ELL population.

In a fourth, or assessment phase, we reflected upon and assessed the modifications made and integrated them into specific guidelines to inform future research. We describe our study in relation to these four phases in the rest of the chapter.

## **2. Development of our conceptual framework**

It was clear to us from the experience in the schools where we conducted our study, and from the literature on literacy for language minority students that the context and problems we faced were complex and multifaceted to warrant the use of a flexible and yet systematic approach to data collection. We strived to develop a successful intervention and to extract useful design principles for other researchers and teachers. To restate our pedagogical goal was to facilitate fourth-grade ELLs' reading comprehension, academic vocabulary, and motivation to read in the content area of science. Our goal was based on the need to develop academic language skills in ELLs (e.g., Bailey, Huang, Shin, Farnsworth, & Butler, 2007; Francis et al., 2006; Scarcella, 2003) and on, what, at the time, constituted only emerging empirical knowledge on the reading comprehension and text-level skills of second-language learners (for a review see Lesaux, Koda, Siegel, & Shanahan, 2006). Our theoretical background came from three main areas of research: (1) reading comprehension for language minority students and ELLs; (2) two empirically driven positions in relation to vocabulary instruction, explicit (e.g., Nation, 2001) and incidental (Nagy, Herman, & Anderson, 1985), which serve as the major contrast for the two interventions developed in this study; (3) reading motivation and its implications for reading comprehension (e.g., Guthrie, Anderson, Alao, & Rinehart, 1999). We briefly present each of these areas next.

### **Reading comprehension for ELLs and language minority students**

By the time we started our study in the Spring of 2009 several empirical studies and at least one national report had indicated that although there was a quite a broad literature on the development of ELL's word level reading skills in early reading, much less was known about their reading comprehension development, and even less about effective interventions to support comprehension in later elementary grades and beyond. In particular, the National Literacy Panel on Language-Minority Children and Youth (NLP; August & Shanahan, 2006) found only five studies that examined reading comprehension performance of language minority students compared to that of their monolingual, native-speaking peers (Lesaux et al., 2006). An overall finding arising from this limited number of studies was that the reading comprehension performance of language-minority students did not appear to develop to the same extent as that of their native-speaking peers (Lesaux et al.). At that time, a few intervention studies addressed comprehension instruction through either cognitive strategy instruction (e.g., Jimenez, 1997; Klingner & Vaughn, 1996; Padron, 1992) or through descriptive approaches that compared ELLs and/or language minority students in terms of their comprehension skills (e.g., Garcia, 1991; Jimenez, Garcia, & Pearson, 1996). However, the majority of intervention studies on second language students' comprehension in the US up to the time of our study had focused on vocabulary instruction, not always including other dimensions of reading comprehension such as cognitive strategy use. Despite the limitations in the extant literature at the time, we learned



quite a bit on vocabulary instruction for ELLs that helped frame our conceptual framework for the study.

### **Vocabulary instruction**

Research on the teaching of vocabulary in English-speaking countries has described vocabulary instruction as *explicit* and *incidental*.

Under the explicit instruction perspective vocabulary words are specifically targeted for instruction, and they are presented through multiple exposures within rich language contexts where word awareness is created through the explicit focus on target words (e.g., Beck, Perfetti, & McKeown, 1982; Blachowitz & Fisher, 2006; Carlo et al., 2004). In our study, the Intensive Vocabulary Instruction (IVI) intervention was developed following research within the explicit instruction approach.

Alternatively, the incidental vocabulary learning hypothesis purports that students learn words from context and develop their vocabulary and academic knowledge through multiple reading-related experiences (Nagy, 1985). Under this hypothesis incidental word learning takes place in small increments through repeated exposures to text and word learning from context is the main mode of vocabulary learning. Amount and frequency of reading are key determinants of a students' vocabulary growth (Nagy et al., 1985). The Contextualized Vocabulary Instruction (CVI) intervention was developed following the principles of the incidental vocabulary learning hypothesis.

### **Reading motivation and comprehension**

Research over the last decade has repeatedly emphasized the impact and contributions of motivation and engagement variables to the development of short-and long-term reading comprehension (Guthrie & Wigfield, 2000; Guthrie et al., 2004). By the time of our study there had been only a few instructional interventions which had successfully impacted comprehension *and* reading motivation in monolingual students (e.g., Guthrie et al., 2004; Wigfield et al., 2008) and even fewer that had explored reading motivation for second language learners (e.g., Arzubiaga, Rueda, & Monzo, 2002; Unrau & Schlackman, 2006). This gap in the literature prompted us to explore a specific teacher support for reading motivation - teacher autonomy support - and its relation to student engagement. Specifically, we examined if the two forms of autonomy support, provisions of academically meaningful choices and teacher rationales for topics and activities (i.e., relevance), were offered with sufficient frequency that they were perceived by students during instruction (i.e., students reports of teacher instances of supports for autonomy and relevance). We then examined if students' perceptions of the frequency of these practices related to student engagement in reading.

### **Conceptualization of our study: The two instructional interventions**

The theoretical framework derived from the three areas of literature that framed our study led us to conceptualize and then develop the two interventions that were then compared and refined with formative data. Each of these are described in detail in the published manuscript (Taboada & Rutherford, 2011) but we briefly described them here.

### **Contextualized Vocabulary Instruction (CVI)**

The CVI instructional framework was based on practices drawn from the reading engagement model (Guthrie et al., 2004) with attention to cognitive strategy instruction, conceptual development, and student autonomy support.

Reading strategies included activating background knowledge, student questioning, graphic organizing, and comprehension monitoring.

The two main classroom practices to enhance students' autonomous learning and reading included fostering relevance and providing meaningful academic choices (e.g., of books, subtopics, strategy to use, etc.). Fostering relevance consisted of a positive perception of learning by having the teacher explain the reasons behind the learning of specific strategies, concepts, and topics. Key concepts in science were introduced as the "anchors" for a topic. Extensive reading of trade books in science (i.e., commercially available books instead of textbook) were key to CVI and to the teaching of comprehension. Academic vocabulary was taught in an implicit way, where students learned word meanings while reading and using comprehension strategies. For example, words such as *camouflage*, *endangered*, and *nocturnal* were learned while asking text-based questions or while working on group-graphic organizers on animal survival. Vocabulary was contextualized because students' would focus on new words in the context of their reading with teacher support, rather than learning these explicitly before or during reading.

### **Intensified Vocabulary Instruction (IVI)**

This intervention was developed on the basis of explicit instruction of academic vocabulary, with a focus on selected target words taught in rich language contexts with a goal of developing word awareness (Blachowitz & Fisher, 2006; Carlo et al., 2004; Graves, 2006). One hundred and four (104) target words were identified for explicit instruction during the 8 weeks of the intervention, with an average of 13 words taught per week. Words were selected according to their centrality for key concepts previously identified. Flashcards with vivid photos of a word on one side and definitions on the other were used to teach words explicitly before and during reading. In addition target words were included in poems that students practiced to develop reading fluency and word learning. Students in IVI were afforded limited choices such as choice of partners to work with and locations of where to work in the classroom. Intentionally, we did not embed cognitive choices and relevance as practices in IVI given that our goal was to determine whether the frequency of these practices related to students' motivation for reading. The same expository and narrative trade books were used in CVI and IVI.

The development of the two interventions for Grade 4 students consisted of (a) pre-selection of science trade books for 8 weeks of instruction (length of the intervention); books were selected according to the two reading levels of the participating students (below and on-grade level) so as to have readability levels that required teacher support for comprehension and vocabulary instruction; (b) providing teachers with 8 week worth of lessons for each intervention; (c) explanations for teachers on the rationales and emphases for instructional activities in the lessons and theoretical background for each intervention. Specifically teachers received a detailed description of the instructional model with lesson plans and student materials (activity charts, flashcards, books, overhead transparencies, etc.) designed by the researchers.

### 3. Development phase

Once we had gone through a first stage of development of the two theoretically-driven interventions we moved onto a second screening phase (Plomp, 2010). During this screening phase the authors checked for essential components within each intervention vis a vis the hypotheses behind each of them.

For example, the researchers checked that in CVI reading activities were consistently characterized by extensive reading and use of strategies and that vocabulary words were related to the key concepts being emphasized.

Similarly we checked that in IVI vocabulary activities were varied along principles of sound and explicit vocabulary instruction but that emphasis on comprehension strategies was only serving vocabulary learning rather than other dimensions of comprehension.

Having developed the intended materials, we focused on the process of teacher selection. As key respondents during the implementation phase it was important to have clear criteria for teacher selection. We approached a local small school district which was known for a high incidence of ELLs and whose teachers have voiced the need for professional development to teach literacy and science in an integrated, efficient way. After meeting with the literacy specialist of one the elementary schools in the district, we asked her to select two teacher volunteers whom she thought could function as mentors to other science teachers after participating in the study. The two volunteer teachers were science teachers new to literacy instruction who volunteered to participate within the six science teachers in the school. The teachers were comparable in terms of their teaching experience, and had an average of 5 to 7 years of teaching science in the elementary grades. Both teachers had at least 3 years experience teaching science to ELLs of different English proficient levels in whole classroom settings. However, neither teacher had used literacy practices to enhance their teaching of science content.

After this second phase, the study entered into the "expert appraisal" phase (Plomp, 2010) in which we spent two half days with each of the teachers to provide opportunities for them to react to the materials and lessons, and the premises or hypotheses behind CVI and IVI respectively. At the end of each half-day each teacher watched segments of lessons on video for each intervention and reacted to specific practices guided by researchers' questions. These questions were geared at essential components of each intervention. Example questions included: "You saw this other teacher on the video teaching questioning as a reading strategy- Did you notice how she led students to include bolded (text) words in their questions after reading? Why would you say she chose to have students use bolded words in their questions?" The CVI teacher, Theresa, explained that this was a good example of teaching new vocabulary words embedded in the questioning strategy. Similar probing questions after and during watching previous lessons were posed to Vivian, the IVI teacher.

Researchers with expertise in EDR recommend establishing quality criteria for evaluation of the intervention at different stages. The two quality criteria that guided the development and implementation phase were *relevance* and *practicality*. Under the criterion of relevance we ensured that each intervention was grounded on previously established scientific knowledge (Plomp, 2010). Under practicality we expected the intervention to be usable in classroom settings with ELLs of intermediate English proficiency just like the groups included in our study.

#### **4. Implementation phase**

The two instructional models, CVI and IVI, were implemented during an 8-week period in the fall, for 35 minutes per day, five days a week in the first period in the morning in one suburban elementary school in the mid-Atlantic United States. The school is located in an area with a rapidly increasing Hispanic immigrant population. The ethnic composition of the school at the time of the study was 43.6% Hispanic, 33.9% White, 12.2% African American, 6.3% Asian/Pacific Islander, 0.2% American Indian, and 3.7% Other. Twenty students were selected from a larger pool of Grade 4 students based on English as a second language (ESL) levels. ESL levels were determined by school/district records using English Proficiency standardized tests. Students in this study were in their majority of intermediate levels of English proficiency. That is, they had relatively fluent levels of oral language proficiency and were one to two grades below in their reading performance.

In addition to the expert appraisal provided by the participating teachers during the development phase, the first author met with both teachers before and during implementation on a weekly basis to provide professional development. During these meetings teachers' questions were answered as they progressed with implementation and feedback from teachers on specific modifications to each intervention was recorded as field notes. Eight observations were conducted for each group (once a week) to ensure that the basic principles of each framework were in place. However, because fidelity of implementation is "the antithesis of formative and design experiments" (Reinking & Bradley, 2008, p. 21), observations were conducted with the double goal of (a) providing feedback to teachers as well as (b) to receive feedback on actual implementation feasibility from teachers. That is, instead of assessing fidelity to the sequence of the activities presented in the original implementation materials, we asked teachers to bring their professional judgment on the teaching of science when they deemed it relevant. In this way, teachers were strongly encouraged to make changes to instruction while taking detailed notes of the change itself and their specific reason for the change. These notes were used as "teacher feedback" on implementation. The first author discussed with each teacher the changes they made and their rationales via semi-structured interviews after each observation.

Observation and teacher interview notes were used as part of the data analysis that helped determine factors that improved or hindered the interventions. In line with EDR modifications to each intervention were chronicled during field observations and organized under themes to capture micro cycles of data collection with formative assessments aimed at improving each intervention.

#### **5. Assessment phase**

We collected both, formative assessment indicators through qualitative data and summative data through quantitative (descriptive statistics) data sources. I focus first on summative/quantitative data as these data allowed pre-, during- and post-intervention comparisons. Qualitative/formative data consisted of modifications to the intervention. As such, these data served to inform the quantitative results obtained as well as to inform the implications of an improved intervention.

##### ***Types of Data***

Summative, quantitative data were collected to assess (a) academic vocabulary, (b) reading comprehension, (c) expository writing, and (d) teachers' supports for students' autonomy. Data for academic vocabulary, reading comprehension, and writing were collected at four points in

time: baseline or pre-intervention, at 4 weeks into the intervention, at the eighth week of the intervention and 3 weeks after the intervention.

With the goal of differentiating findings for different readers we examined these data according to two reading levels (based on school records): at or below the 2.5 grade-equivalent reading level and above the 2.5 grade-equivalent level. Data analyses for each intervention were conducted according to these two reading levels. Teachers' supports for student autonomy (choice and relevance) were collected at eight points in time, three times during baseline (pre-implementation period; baselines 1, 2, and 3) and five times during the intervention. These times coincided with the eight observations when qualitative data were collected.

As mentioned, qualitative data consisted of field logs and research briefings from classroom observations and teacher interviews (questions and feedback).

Detailed descriptions of each of the instruments used for both types of data are included in the original study (Taboada & Rutherford, 2011).

### **Findings from CVI and IVI**

Findings from our quantitative data were limited to descriptive statistics (group means) due to our small sample size. Similar to approaches used in single subject designs (Horner et al., 2005), we compared student performance during the intervention with performance at baseline. Means for academic vocabulary, comprehension, and writing across four times were compared for each group. First, we assessed students at baseline or pre-intervention to determine whether the reading level groups were different from each other to begin with. We found that within each group (2.5 and below, lower readers, and above 2.5 reading level, higher readers), students had comparable scores on the academic vocabulary, reading comprehension, and expository writing measures. With respect to academic vocabulary lower readers were consistently below their higher-reading level counterparts across interventions. However, across time students in IVI showed more steadily growth in vocabulary than students in CVI, and this was evident after only 3 weeks of intervention. Further, by the 8 weeks of intervention the gains in vocabulary for IVI students were evident for both low and high readers. Students in CVI, in contrast, showed positive trends in vocabulary growth at all three assessment times after baseline, but were consistently below their counterparts in IVI. Qualitative data from teacher feedback supported these findings with the IVI teacher indicating the advantages of IVI on vocabulary learning, whereas the CVI teacher indicated some of the challenges of linking vocabulary teaching to strategies and concepts (i.e., this challenge became a modification to the intervention).

With reading comprehension we also found that across interventions students had comparable scores with higher readers being slightly above lower readers at baseline and beyond. However, different from academic vocabulary performance, students in CVI consistently had higher reading comprehension scores than students in IVI, both, across the three times and across reading level groups. Further, the most pronounced difference between lower and higher readers across both interventions was found at 3 weeks after the intervention, with students in CVI scoring consistently higher than students in IVI irrespective of their reading status/level. Qualitative data from observations and two teacher interviews supplemented these quantitative findings by adding information on CVI students' growing ease with responding to inferential (rather than just literal) comprehension questions during instruction. This finding could, in part, be attributable to CVI students marked growth on reading comprehension. In relation to expository writing, we found once again, that all CVI students showed consistent improvement from pre- to post-intervention with less of an upward trend for the IVI students.

Teacher autonomy-supportive practices were analyzed by examining frequencies of teacher affordances for choice of partners to work with, academically meaningful choices (e.g., what section of the book to read; what science concept to display graphically) and supports for relevance (e.g., explanations and rationales for strategy use). Frequencies of these behaviors were collected across the eight observations. We found that during the three observations at baseline neither the CVI nor the IVI teacher offered academic choices, but the CVI teacher, Theresa, had at least two instances of fostering relevance. Changes observed during intervention indicated that the CVI teacher consistently offered more academic choices than the IVI teacher and consistently had more instances of fostering relevance than the IVI teacher. However, the actual types of academic choices varied according to the practices fostered in each intervention. Relevance explanations were also more prevalent in CVI and these increased over time as Theresa, the CVI teacher, became more familiar with the purpose of the practice itself. Our last quantitative analyses examined students' perceptions of supports for their autonomy in the classroom and their reading engagement. On average students in the CVI condition perceived higher levels of autonomy-supporting behaviors than students on the IVI condition and these had a stronger relationship with students' reading engagement (measured as teacher reports) for students in CVI than for students in IVI.

### **Modifications to the interventions**

Central to the design of EDR within our study was the gathering of qualitative data (i.e., observation notes, interviews, and teacher-researcher feedback loops) that would help us answer the question of what were the factors that inhibited or enhanced the implementation of each intervention while trying to achieve the pedagogical goal. We learned as much about the data itself as from the actual process of data informing changes to the interventions. That is, before conducting our study we envisioned modifications to the intervention that would proceed through well-defined cycles and sequential steps that would be derived from data and inform future instructional steps. However, during the implementation phase of the study we found this process to be more "fluid" because modifications and changes to the intervention resulted from a combination of responding to the intervention based on the "intuitive demands of the moment" (Reinking & Watkins, 2000, p. 399), an examination of research notes from observations and even more so from the evolving information received from each teacher through interviews. The confluence of these three data sources led us three main modifications to the interventions: (a) mode of delivery of vocabulary instruction, (b) mode of delivery of conceptual and strategy instruction, and (c) provision of academically meaningful choices.

In the original study (Taboada & Rutherford, 2011) we described the nature of each modification and the degree to which they changed each intervention.

We do not concentrate on them here due to space, however, what is illustrative of our experience with EDR is that the iterative nature of data cycles allowed changes to the intervention that helped refine it and derive instructional principles that informed practice and, possibly, theory about comprehension instruction for students with the characteristics of the ELLs in this study. For instance, when it came to modifications to vocabulary instruction in CVI we found out that the degree of explicitness versus implicitness needed to be further defined. If words were left to be learned directly from text students who did not have comprehension skills to make inferences ended up not learning the new words. On the other hand, explicit teaching of all new words in a book or section would border on the explicitness and word-centered instruction promoted in IVI, thus conflicting with the implicit vocabulary hypothesis behind CVI. This adjustment needed a few observations and interviews with Theresa, the CVI teacher, in

order to make the changes effective for practice while also not distorting the core principles behind CVI. Specifically, notes from interview data with Theresa indicated that:

*"I am unclear as to whether I should highlight words at the beginning of the lesson, or let students find them during reading and come ask me about their meaning if this is not in the glossary. I also struggle as to how to present words in relation to the key concepts and comprehension monitoring."*

The CVI teacher's inquiries led to changes in instruction. Specifically, after reviewing what the main science concepts were for the week (e.g., *social animals, colonies, animal communities*), the teacher and researcher revised the notion of comprehension strategies as tools to help students "excavate" text. There was also a long discussion that the ultimate goal of reading was to help students build conceptual knowledge in science.

Leading the lesson by introducing the core concepts, followed by explicit teacher modeling the reading strategies for the week and posting target vocabulary words from text, helped the CVI teacher structure her teaching. Revised lesson plans were put in place in such way that the CVI teacher had clear objectives for science content, enhancing comprehension and vocabulary learning. We engaged in a similar iterative cycle with Vivian, the IVI teacher, on this and the other two modifications. These iterative cycles also provided the opportunity to reflect and establish what dimensions of each intervention were "non-negotiable" or essential components at the core of each intervention that could not be changed. For CVI these included the explicit teaching of comprehension strategies and the provision of academically meaningful choices. For IVI the core elements included the explicitness of vocabulary instruction and alternating vocabulary activities that kept the focus on word meaning (for a detailed description of modifications to the interventions please see the original study Taboada & Rutherford, 2011).

All in all, we believe that it was the systematic analyses of the qualitative data and the reflection together with each teacher that allowed us, as researchers, further understand the feasibility of each intervention as well as the summative findings previously described. Had we not have the iterative data cycles afforded within EDR we, most likely, would have established a direct relationship between the theoretical principles behind each intervention and the summative results obtained. In doing so, we would have missed the understanding of the nuances of instruction within each framework, and, perhaps, most importantly, the *how* and *why* certain components worked, or did not work, would have been lost.

## **6. Yield from the project**

Fostering literacy in English for ELLs has become a necessity for practitioners, policy makers, and literacy researchers alike. This need is even more prevalent when ELLs are faced with the challenges of reading and developing knowledge in subject areas where they need to learn English language structures and content in depth. Researchers have focused attention on the integration of reading comprehension with subject matter for at least two decades now (e.g., Guthrie et al., 2004; Snow, 2002). In this study we approached the integration of comprehension and vocabulary instruction in the content area of science from two theoretical perspectives that could be applicable to instructional practices with ELLs of English intermediate proficiency.

The benefits of approaching our study using EDR included having had a clear direction (through an unambiguous pedagogical goal) while also having the flexibility of exploring modifications to the interventions through the use of summative and formative data. Our quantitative findings shed light on implications for literacy practices for ELLs, but these were qualified and expanded by our qualitative results, which explicitly informed modifications to the interventions.

First, our quantitative, descriptive results indicated slightly higher results in academic vocabulary for students in the IVI instructional group, for both high and lower readers. Although CVI students also showed increasing academic vocabulary across data points for both reading levels, these were consistently lower than scores for IVI students. However, summative findings were reversed on reading comprehension, with students in CVI showing marked and higher improvements in the CVI group for both higher and lower readers. When we examined these results and looked at item types, we found that CVI students improved in both literal and inferential comprehension items, whereas IVI students improved mostly on the literal items. In our original study we speculated on the reasons for these differences in comprehension across the two groups, with a possible explanation being that IVI students' lower comprehension scores may lie in the fact that instruction led students to be more perfunctory readers due to the lack of explicit strategy instruction.

By the same token, we reasoned, students in the IVI group may have developed a large body of specific vocabulary (as evident on the vocabulary measures), but when faced with the complex task of comprehension, vocabulary may have been a necessary but an insufficient condition to be successful in the task. That is, it is possible that students in IVI learned words in more superficial ways than students in CVI due to the lack of contextualization of these words in a broader conceptual framework.

Although these are speculative explanations and we are aware that the hypothesis of (more) superficial learning of words in IVI would have had to be tested over time (e.g., testing for word breadth and depth at two given time points after the interventions), we recognize that had we not had the iterative data cycles (i.e., teacher interviews and observations) we would have not learned about the nuances of both vocabulary and comprehension instruction within and across interventions. We see this interplay between data cycles of qualitative data as informing design principles that informed and changed each intervention as these took place over the 8 weeks. A case in point of a design principle derived from data is how the teaching of vocabulary words changed over time in CVI. That is, despite the CVI teacher's, Theresa, initial difficulties with teaching vocabulary incidentally, after modifications were put in place, we observed a seamless interplay between strategy and academic vocabulary instruction. We believe that had those challenges not have been present, informative changes to the intervention would not have taken place.

## **7. Lessons learned**

Our study led us to conclude that the teaching of specific academic words under both types of frameworks, implicit and explicit, can be effective depending on context and length of the intervention. However, we also learned that there were benefits on reading comprehension of the CVI approach. Also, both quantitative and qualitative findings indicated the benefits of CVI on students' perceptions of teachers' support for student autonomy and their link to reading engagement. Therefore, we ended up with a multifaceted set of findings that informed theoretical principles of instruction for ELLs with the characteristics of those in our sample. That is to say: Instruction that fuses comprehension instruction with incidental vocabulary teaching and supports for students' autonomy is conducive to engagement in reading in ELLs in the latter elementary grades. However, explicit instruction of vocabulary (such as in IVI) has benefits for ELLs' vocabulary development, at least in the short term. In looking at the longer term, we would need to explore instructional practices that strike the right balance among strategy instruction, key concepts, and academic vocabulary in ways that consider both explicit and implicit instruction.



In our current work, we are exploring the right balance of these practices by paying specifically attending to the age of the population of interest (i.e., middle school), English language proficiency levels, content background knowledge and literacy in both ELLs' English and first or home language. We believe that attention to these demographic and educational variables, as well as to the specific context in which we intend to develop our current intervention is crucial to succeed in designing interventions that enhance practice and refine theory.

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## The Development of an RME-based Geometry Course for Indonesian Primary Schools

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# 8. The development of an RME-based geometry course for Indonesian primary schools

Ahmad Fauzan, Tjeerd Plomp & Koeno Gravemeijer

## Abstract

*The aim of this study was to develop and implement a valid, practical, and effective RME-based geometry course for Indonesian primary schools using design research approach. The research activities were divided into three stages namely front-end analysis, prototyping stage, and assessment stage that were conducted in a four year period. The focus of the chapter is to present detail and rational regarding the three stages. The result of the study was a high quality RME-based geometry course for teaching geometry at grade 4 in Indonesian primary school consisted of teacher's guide and student book. In the products lies the local instructional theory for teaching geometry that was effective for improving pupils' understanding, reasoning, activity, creativity, and motivation.*

## 1. Introduction to the problem

The study reported in this chapter has been conducted in the period 1998 - 2002. At that time the quality of mathematics education in Indonesia, especially in primary and secondary education, was considered poor (see Soedjadi, 1992, 2000), whilst the mathematics learning and teaching process in the classrooms was dominated by the traditional method (see Somerset, 1997; Marsigit, 2000). The traditional way of teaching had a negative influence on the pupils' attitudes towards mathematics which means that most pupils did not like to learn mathematics, and that some of them were even afraid of mathematics (Marpaung, 1995, 2001). This study aimed to explore whether another approach to mathematics education could address these shortcomings by developing and implementing an exemplary course viz. *Realistic Mathematics Education (RME)-based geometry course*, for teaching and learning the topic Area and Perimeter at Grade 4 in Indonesian primary schools.

The focus of the study was to develop and implement a valid, practical, and effective RME-based geometry course by applying design research approach. These processes were guided by the main research question:

*What are the characteristics of a valid, practical and effective RME-based geometry course for learning and teaching the topic Area and Perimeter at Grade 4 in Indonesian primary school?*

## 2. Context of study: mathematics education in Indonesia

The general goals of mathematics education in Indonesian primary education were phrased as follows

- Preparing the pupils to be able to deal with the dynamic changes of world situations effectively and efficiently through practical works based upon logical reasoning, rational and critical thinking, caution and honesty.
- Preparing pupils to be able to use mathematics and mathematical reasoning in their everyday life and in studying other sciences.

After reading the lofty goals, questions arose as to why the *quality* of mathematics education in Indonesian primary schools was still poor. The following paragraphs will discuss some primary causes of poor quality of mathematics education in Indonesian primary schools.

The first cause was that the lofty goals have become blurred when they came into practice. The specific instructional objectives from Grade 1 till Grade 6 were still dominated by remembering facts and concepts and reproducing them verbally, studying computational aspects, and applying formulas.

The second reason was poor quality of mathematics textbooks. In the textbooks, many abstract concepts were introduced without paying much attention to aspects such as logic, reasoning, and understanding (Soedjadi, 2000). The topics that were taught seem far removed from pupils' daily life. Even the teachers themselves sometimes did not know the usefulness of the topics they have taught.

A third reason for poor quality of mathematics education in Indonesian primary schools was related to teachers. Most teachers preferred a traditional approach in teaching mathematics. In general, the climate in Indonesian classrooms (see Fauzan, 2000, 2001; Fauzan, Slettenhaar & Plomp, 2002a, 2002b; Somerset: 1997), was similar to that in several African countries as was summarised by De Feiter and Van den Akker (1995) and Ottevanger (2001) as follows:

- 'chalk and talk' is the preferred teaching style;
- emphasis on factual knowledge;
- lack of learning questioning;
- only correct answers are accepted and acted upon;
- whole-class activities of writing/there is no practical work carried out.

The impact of the situations described above was that most students dislike learning mathematics because they were not learning the mathematics they need. They also did not have the opportunity to learn significant mathematics, and lack commitment towards or were not engaged in existing curricula. The other impact was that the students' achievements in mathematics were poor from year to year (see Fauzan 2002). The poor performance of Indonesian students could also be seen from the Trends in International of Mathematics and Science Study (TIMSS) report (Mullis et al., 2000). Related to geometry, some findings indicated that geometry tended to be the most difficult among the mathematics topics not only for students but also for teachers (see Fauzan, 1996,1998; Herawati, 1994; Amin, 1995). The poor performance of the students in geometry and their negative attitude toward geometry became the big challenges for this study. These issues together with the fundamental problems mentioned in section 1 lead to the following questions.

- *How to design a high quality course that could promote not only pupil learning but also pupil's attitude in learning mathematics?*
- *How to support teachers in implementing the course?*

The questions, which became the main focus in this study, were addressed in a research project aimed at developing and implementing an RME-based geometry course.

### **3. Design research as the research approach**

This study built upon two "schools of thought" of design research. The first one emerges in the context of more general design and development questions (see Van den Akker, 1999; Van den Akker & Plomp, 1993; Plomp, 2009; Richey & Nelson, 1996). The second one developed within the area of mathematics education by mathematics educators in the Freudenthal Institute (FI), The Netherlands (see Freudenthal, 1991; Gravemeijer, 1994a, 1994b, 1999). In the following part we will characterize how we perceived and used design research in this study.



### What is design research?

According to Van den Akker & Plomp (1993), design research is characterized by its twofold purpose:

- Development of prototypical products (curriculum documents and materials), including empirical evidence of their quality.
- Generating methodological directions for the design and evaluation of such products.

This study was about development and implementation of an RME-based geometry course that fits the first purpose.

Richey & Nelson (1996) and Van den Akker (1999) distinguish two types of design research.

These are summarized by Nieveen et al. (2006) as development studies and validation studies.

- *Validation studies* have a focus on designing learning environments or trajectories with the purpose to develop and validate theories about the process of learning and how learning environments can be designed. Validation studies aim at advancing learning and instruction theories, such as Realistic Mathematics Education (Gravemeijer & Cobb, 2006).
- *Development studies* aim at design principles for developing innovative interventions that are relevant for educational practice. "Development studies integrate state-of-the-art knowledge from prior research in the design process and fine-tune educational innovations based on piloting in the field. ... By unpacking the design process, design principles that can inform future development and implementation decisions are derived." (Nieveen et al., 2006: 153).

Considering that this study was aiming at developing a high quality RME-based geometry course, it may be categorized as development study type of design research. But as this research also aimed at validating whether the constructivist approach of Realistic Mathematics Education could be successfully applied in the context of Indonesian mathematics education, this research was a validation study type of design research as well.

Important activities in design research are its cyclic nature (of analysis design, development, implementation, evaluation and reflection) and the use of formative evaluation as a key activity to establish evidence of product quality and to generate guidelines for product improvement (Ottevanger, 2001). Related to this, Nieveen (1997) and Van den Akker (1999) mentioned three main stages or phases in design research (see also Plomp, 2009), which are *front-end analysis/preliminary investigation*; *prototype phase*, and *assessment phase*, consisting of summative evaluation of the final product. Throughout all these activities, a systematic reflection on the development methodology has to take place to produce design principles (Plomp, 2009).

Following these activities and the work of Nieveen (1997) and Ottevanger (2001), the study was divided into three stages namely *front-end analysis*, *prototyping stage*, and *assessment stage*.

During the prototyping stage, the design research approach proposed by Freudenthal Institute (see Gravemeijer 1999; and Gravemeijer & Cobb, 2006) was applied. This approach was followed in developing the content of RME-based geometry course, especially in designing the instructional sequences. Freudenthal (1991, p. 161), in relation to the development of RME, defines design research as:

*"Experiencing a cyclic process of development and research so consciously, and reporting on it so candidly that it justifies, and that this experience can be transmitted to others to become like their own experiences"*

Gravemeijer (1999; and see also Gravemeijer & Cobb, 2006) states that in this approach researchers direct their attention to developing instructional sequences in learning mathematics. To do so, they start with thought experiments, thinking about the learning route that will be

passed through by pupils. By reflecting on the results of instruction experiments in which the results of the thought experiments are tried out, they continue with the next thought experiment. Researchers in this approach have a long term learning process in mind. In this long-term process, the subsequent of thought and instruction experiments are connected. This situation leads to the description that development can be seen as a cumulative cyclic process, as it is shown in Figure 1.

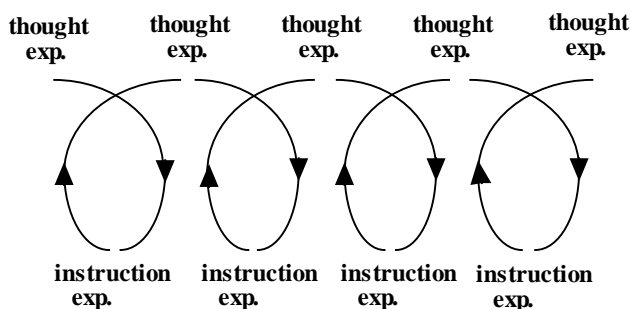


Figure 1: Design research as a cumulative approach (source: Gravemeijer, 1999)

The cycles of the thought and instruction experiment described above indicate the activities carried out on a daily basis developing a learning sequence. For example, the second thought experiment is conducted based on the results of the first instruction experiment. The results of this thought experiments are tested through the second instruction experiment on the next day. This process is continued until the instructional sequences, consisting of a number of lessons for teaching a mathematics topic that work well, are developed. The instructional sequences are called *local instructional theories*. Gravemeijer and Cobb (2006) call the daily basis of the development a micro cycle and the development of the whole learning sequences a macro cycle (see Figure 2).

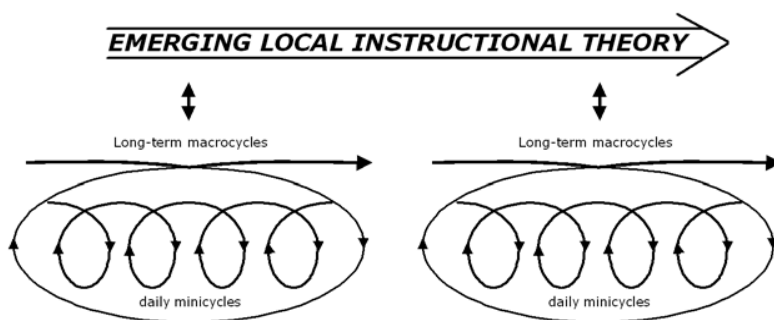


Figure 2: Micro and macro cycles of design research (Gravemeijer & Cobb, 2006)

Our study combined the two approaches in design research, as is summarized in Table 1.

Table 1: The summary of design research

<b>Type of research</b>	Design research (development and validation studies).
<b>Main focus</b>	Design and research on the RME-based geometry course and testing of the characteristics.
<b>Aims</b>	To develop a high quality RME-based geometry course that was suitable for learning and teaching the topic Area and Perimeter at Grade 4 in Indonesian primary schools.
<b>Expected results</b>	1. A high quality RME-based geometry course. 2. Lesson learned about: <ul style="list-style-type: none"> <li>• characteristics of a high quality RME-based geometry course;</li> <li>• development process of the RME-based geometry course;</li> <li>• implementation process (how teachers teach in the classrooms and how pupils learn);</li> <li>• the improvement on pupils' understanding, reasoning, activity, creativity, and motivation;</li> <li>• the local instructional theory for learning and teaching the topic Area and Perimeter.</li> </ul>

A high quality RME-based geometry course referred to three quality criteria namely *validity*, *practicality* and *effectiveness* (Nieveen, 1997; 1999).

- *Validity* refers to the extent that the design of the intervention include "state of the art knowledge" (content validity) and the various components of the intervention are consistently linked to each other (construct validity).
- *Practicality* refers to the extent that users (teachers and pupils) and other experts consider the intervention as appealing and usable in normal conditions.
- *Effectiveness* refers to the extent that the experiences and outcomes from the intervention are consistent with the intended aims.

### The stages of the research

As mentioned in the previous section, the design research was conducted in three stages (see Figure 3). These processes were realized in a four-year research, which included three field-work periods in Indonesian primary schools.

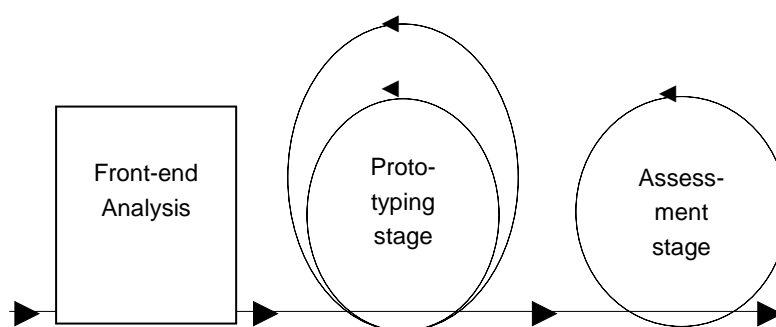


Figure 3: The general research design

In the design, the prototyping stage is presented in two cycles to indicate that there were two consecutive prototypes of the RME-based geometry course that were developed during this stage. The cycles in the design also include the formative evaluations that were conducted in each stage of the study.

## 4. The results of the study

Following the phases described in Figure 1, the focus, research activities, data collection techniques, and the results of the study in each stage will be elaborated in the next sections.

### Front-end analysis

The purpose of front-end analysis is to get a picture of the starting point and the potential end points of the course. The work done in this stage included context and problem analysis, literature review, and analysis of available and promising examples.

The context and problem analysis was conducted by doing several activities such as review of Indonesia curriculum documents and related research results, classroom observations, interview with principals, the fourth grade teachers and some pupils from six primary schools (3 schools in Padang, West Sumatra and 3 schools in Surabaya, East Java). The schools have been chosen purposively by considering the quality of the schools (high, middle, and low). The summary of these activities has been described in section 2.

The literature review on the RME theory gave the pedagogical direction to design the first draft of the RME-based geometry course on the topic *Area and Perimeter* for pupils at Grade 4 (pupils around 10 years old). As it was designed based on the RME approach, it needed to reflect the three key principles of RME: guided reinvention, didactical phenomenology and emergent models (Gravemeijer; 1994a, 1999).

The guided reinvention principle was applied to sequence the learning trajectory so that pupils could learn the topic Area and Perimeter as intended based on the RME point of view. The second RME principle was realized by using contextual problems as starting point so that the pupils would experience the process of horizontal and vertical mathematization (see Gravemeijer, 1999). The contextual problems would also facilitate the pupils to use their own models (*model of*) to solve the problems until one of them emerges into a formal way to solve a mathematical problem (*model for*).

Based on context analysis (Indonesia) and review of literature and related documents (see Fauzan 2002), it was decided to design an RME-based geometry course with the vision was to broaden the concept of Area and Perimeter. The rationale for broadening of the concepts was that when we talk about Area and Perimeter in our daily life, we are not only dealing with regular shapes such as squares, rectangles or triangles, but also irregular shapes or surfaces of 3-dimensional objects such as cakes, lands, and tiles.

The vision of the RME-based geometry course was elaborated further by broadening the concepts of Area and Perimeter through the following aspects.

- *Relating Area and Perimeter to other "magnitudes"*  
The concepts Area and Perimeter are frequently involved in our daily activities. For that reason, it is considered to be important to relate them to other magnitudes such as *costs, weight, paint, rice field, cake and fence*. By relating the concepts to other magnitudes, it gives the pupils the opportunity to learn the concepts in a more meaningful way.
- *Introducing the exchange of measurement units as a counting strategy*  
In most literature on *traditional mathematics* the square is introduced as the only measurement unit. However, in reality we use various non-square measurement units, such as rectangle or triangle tiles. So that, introducing the exchange of measurement units as a counting strategy would be useful for helping pupils to understand area.
- *Investigating the relation between Area and Perimeter*  
There is a strong belief that Area and Perimeter are directly proportional to each other (Gravemeijer, 1992), in which people think that the bigger the perimeters the bigger the areas, or vice versa. To prevent pupils from this confusion, in the RME-based geometry course the concepts of Area and Perimeter are taught consecutively.

- *Connecting measurement units to reality*  
This aspect of broadening the concept of area is to make the pupils aware that many objects in their real life can be used as a measurement unit. Moreover, relating the measurement units such as  $\text{cm}^2$ ,  $\text{m}^2$ , and  $\text{km}^2$  to reality (for examples, the sizes of: the thumb nails, the surface of the tables, the forests) will help the pupils to understand the idea of the relative sizes of those measurement units as well as the relationship between one measurement unit and the others.
- *Making pupils aware of the model-character of the concept (approximation, neglecting irregularities)*  
Teaching the topic Area and Perimeter in traditional mathematics causes pupils to think that areas of the rectangular shapes are always the product of two lengths and that learning the topic Area and Perimeter is identical with applying the formulas (see Romberg, 1997). In reality we mostly deal with irregular shapes. It means that we need to teach pupils about the idea of approximation regarding Area and Perimeter, in order to make them aware that the measurement is never exact.
- *Integrating some geometry activities*  
In traditional mathematics, the geometry activities for learning the topic area are dominated by counting grids and applying the formulas. In the RME-based geometry course some geometry activities are involved such as *re-shaping*: cutting a figure into pieces and reallocating these pieces to get another shape, and *tessellation*: arranging tiles in various ways. Re-shaping is considered as an important activity in the RME-based geometry course because it not only makes it easier for pupils to find areas of various geometry shapes but also makes them aware of the conservation of area. Meanwhile, tessellation will make the pupils aware of the possibilities of compensation. Gravemeijer (1992) argues that the tessellations are just like an excursion in geometry, and at the same time it makes the pupils realize that area units do not have to be squares.
- *Involving reallocation problems*  
*Reallocation* is a concept in which the area of a shape remains the same when it is reshaped. By working on the reallocation problems, for examples the problems about tessellations, pupils will better understand that: a shape can be seen as the sum of other shapes or as a portion of another shape; a shape can also be arranged to form a different shape by cutting and pasting. The concept of reallocation will also help pupils to realize that the objects that have the same areas can have various shapes.

Based on the vision and the review of related documents, such as the realistic geometry textbooks developed from the Wiskobas project in The Netherlands (see Gravemeijer, 1994a; Klein, 1999; Treffers, 1991), the paper entitled *Reallocation* written by Gravemeijer (1992), and the book with the same title used in the project Mathematics in Context (MiC) in the USA (see NSF, 1997), the hypothetical learning trajectory in the RME-based geometry course was designed. The detail of the hypothetical learning trajectory can be found in Fauzan (2002).

### **Prototyping stage**

A prototype is a preliminary version or a model of all or a part of a system before full commitment is made to develop it (Smith, 1991). According to Nieveen (1997) the term "develop" in this definition refers to the construction of the final product. So, the prototypes are all products that are designed before the final product will be constructed and fully implemented in practice.

As applying the RME principles into Indonesian context needed some adjustments, the prototyping approach was used in this study because this approach gives the opportunity to

develop an RME-based geometry course fitting the Indonesian context (see Goodrum, Dorsey & Schwen, 1993; Nieveen, 1997; Shneiderman, 1992; Tessmer, 1994). Two prototypes of the RME-based geometry course for learning and teaching the topic Area and Perimeter were developed in this stage namely, *prototype 1* and *prototype 2*. The latter was built upon the experiences in prototype 1. Each prototype consisted of a student book and teacher guide for ten lesson periods (one lesson takes 70 minutes). The way that the prototypes were developed followed the design research approach of Freudenthal Institute (see *section 3*).

#### ***Prototype 1 of the RME-based geometry course***

It was important to determine that the draft course would fit not only the Indonesian curriculum, but also the ideas underlying RME. For this purpose, prototype 1 was reviewed by two Dutch RME experts (in RME and geometry) and three Indonesian subject matter experts (in mathematics curriculum and also familiar with RME).

The main focus of developing prototype 1 was to reach a valid RME-based geometry course. This activity was guided by the next research question:

*What are the characteristics of a valid RME-based geometry course for learning and teaching the topic Area and Perimeter at Grade 4 in Indonesian primary schools?*

The investigation into the content validity of the RME-based geometry course was focused on the following issues:

- *Does the content of the RME-based geometry course include the subjects/topics that are supposed to be taught for topic Area and Perimeter?*
- *Does the content of the RME-based geometry course reflect the RME's key principles?*
- *Does the RME-based geometry course reflect the RME's teaching and learning principles?*
- *Does the RME-based geometry course reflect the important aspects of realistic geometry?* (see De Moor, 1994).

Meanwhile, the construct validity or the internal consistency of the RME-based geometry course dealt with the following questions.

- *Is the content of the RME-based geometry course sequenced properly?*
- *Is the content well chosen to meet the objectives/goals described in the beginning of each lesson?*

Research activities in answering the questions above are summarized in Table 2.

Table 2: The summary of evaluation of prototype 1

Focus of evaluation (What?)	The purposes of valuation (Why?)	Evaluation activities (Method (How?))	Instruments
Validity of the RME-based geometry course, focused on the content and construct validity.	To test the characteristics of the RME-based geometry course whether they meet the criteria mentioned in the questions above.	Interview and discussion with the Dutch RME experts and Indonesian subject matter experts, classroom observations, analyzing pupil's portfolios.	Interview guidelines, observation scheme.
The learning and teaching process using the RME-based geometry course.	To assess whether the hypothetical learning trajectory works as intended.	Classroom observations in two schools and interviews with pupils and teachers from those schools.	Observation scheme, interview guidelines.

Based on the results of experts' reviews, it was concluded that the RME experts approved of the content and the construct validity of the RME-based geometry course as well as the hypothetical learning trajectory for learning and teaching the topic Area and Perimeter. Nevertheless, the RME experts recommended that some contextual problems should be improved in order to strengthen the conjectured learning trajectory.

After the revision process, prototype 1 was implemented in two primary schools in Indonesia. The reason to choose the two schools was because they had different conditions. The pupils from school 1 were very heterogeneous in mathematical ability, while the pupils in school 2 were rather homogeneous. It was assumed that the variations between the schools would enrich the results of the classroom experiments. Another reason was the willingness of the two schools, especially the teachers and principals, for collaboration.

Some problems emerged during classroom experiments such as:

- Some pupils could not finish working on the given contextual problems because of several problems regarding their negative attitude (such as very dependent to the teacher and not used to working in-group) and the time constraint.
- There were some contexts that were not used by the pupils when they were solving some contextual problems. This was because the statement in those problems did not guide the pupils to use the contexts. See Fauzan (2002) for more details.

### **Prototype 2 of the geometry course-based RME**

The results of the classroom experiments as described in the previous section led to the development and implementation of prototype 2 of the RME-based geometry course. The main focus of the development and implementation of prototype 2 was to investigate the validity and the practicality of the RME-based geometry course. The validity was re-investigated at this stage because the results of the development and implementation of prototype 1 showed that the validity of the RME-based geometry course needed to be improved. The research question for this stage of the study was:

*What are the characteristics of a valid and practical Geometry course-based RME for learning and teaching the topic Area and Perimeter at Grade 4 in Indonesian primary schools?*

As mentioned by Van den Akker (1999), practicality refers to the extent that users (and other experts) consider the intervention as appealing and usable under normal conditions. It means

that the RME-based geometry course should meet the needs and wishes of pupils and teachers at Grade 4 in Indonesian primary schools. For this purpose, some questions were formulated to investigate the practicality of the RME-based geometry course, for examples:

- *Has the RME-based geometry course potential for developing student's understanding?*
- *Is the student book easy to use?*
- *Does the learning process progress as intended?*
- *Do teachers use the teacher guide as intended?*

Research activities in developing and implementing prototype 2 of the RME-based geometry course consisted of two cycles, namely expert reviews and classroom experiments as has been elaborated in Table 3.

*Table 3: The summary of evaluation of prototype 2*

<b>Focus of evaluation (What?)</b>	<b>The purposes of evaluation (Why?)</b>	<b>Evaluation activities (Method (How?))</b>	<b>Instruments</b>
Validity of the RME-based geometry course (continued).	To test the characteristics of the RME-based geometry course to see whether they meet the criteria (see the questions in section 5a).	Interview and discussion with two Dutch RME experts and three Indonesian subject matter experts, classroom observations.	Interview guidelines, observation scheme.
Practicality of the RME-based geometry course.	To check whether the learning and teaching process using the RME-based geometry course meet the criteria (see the questions before Table 3).	Interview and discussion with the Dutch RME experts, Indonesian subject matter experts, teachers, principals, supervisors and pupils, and classroom observations in two schools.	Interview guidelines, observation scheme.

Prototype 2 of the RME-based geometry course was implemented (by the researcher as a teacher) in two primary schools from two different provinces, after the revision process. The main reasons for choosing the two schools were similar to those when implementing prototype 1. Moreover, the cultures of the two places were different, especially in working habits, so this would probably enrich the results of the research.

The results from the experts' validation showed that prototype 2 of the RME-based course met the criteria of the content and construct validity. However, the experts did have suggestions such as:

- *add the contextual problems that would show the idea of approximation and that the results of measurements are never exact;*
- *relate Area and Perimeter to other magnitudes, reshaping, adding and subtracting area.*

The findings from the classroom experiments also indicated that the conjectured learning trajectory for the topic Area and Perimeter worked as intended for most pupils. Based on these results it was concluded that the RME-based geometry course met the criteria of the *content* and *construct validity*. It means that the local instructional theory designed in the RME-based geometry course was valid for learning and teaching the topic Area and Perimeter.



The experts, supervisors, and principals agreed that prototype 2 of the RME-based geometry course had potential to develop pupils' understanding, reasoning, activity, creativity and motivation. They also agreed that the RME-based geometry course would be usable and useful for teaching the topic Area and Perimeter. Based on the classroom observations, it was observed that the RME-based geometry course could be used by the pupils and teachers as intended. The results from the interviews with the pupils and teachers also indicated that the student book and teacher guide were easy to use. Based on these results it could be concluded that prototype 2 of the RME-based geometry course reached the criteria of the practicality. At this stage of the study, the practicality of the RME-based geometry course was only evaluated in two schools in which the researcher acted as teacher. Therefore, the course needs to be evaluated in more schools in the assessment stage by involving teachers in the implementation processes, to generate more evidence about its practicality. In addition, the effectiveness of the RME-based geometry course had also to be investigated in order to show its effect on the pupils' learning.

### **The assessment stage**

After the development and implementation of two prototypes of the RME-based geometry course during the prototyping stage, this study moved to the last phase called the assessment stage. In this stage the *final version* of the RME-based geometry course was implemented in five Indonesian primary schools in order to gain more insights in the practicality and effectiveness. The term *further insights* means two things: first, the number of schools for the classroom experiments would increase, and five additional classroom teachers would be involved in the implementation to find out whether they could teach the RME-based geometry course. Second, this assessment stage would lead to an opportunity to further evaluate the conjectured learning trajectory.

In preparing the teachers to be able to implement the RME-based geometry course, a series of workshop-based doing mathematics activities (see Gravemeijer, 1994a; Treffers, 1991) and reflections after the teaching practices have been conducted (see also Fauzan, 2002). The research question for the assessment stage was:

*What are the characteristics of a practical and effective RME-based geometry course for learning and teaching the topic Area and Perimeter at Grade 4 in Indonesian primary schools?*

The RME-based geometry course reached the effectiveness criteria if it would have a positive impact on the pupils and teachers in learning and teaching the topic Area and Perimeter. These criteria were measured using four of five levels of effectiveness mentioned by Kirckpatrick (1987) and Guskey (1999, 2000) namely *participants' reaction*, *participants' learning*, *participants' use of new knowledge and skills*, and *impact (the learning outcomes)*. The participants in this study were the pupils and teachers. The level *impact to organization* was not used to assess the effectiveness of the RME-based geometry course because it was not applicable to this study. The levels of effectiveness in this study were elaborated upon by posing the following questions:

- *Participants' (pupils and teachers) reactions:*
  - Did they like the RME-based geometry course?*
  - Was their time well spent?*
  - Was the RME-based geometry course useful for them?*
- *Participant's learning:*
  - Did the teachers and pupils acquire the intended RME knowledge?*

- *Participant's use of new knowledge and skills:*  
*Did the teachers and pupils effectively apply the RME knowledge and skills?*
- *Pupils' learning outcomes:*  
*Were the pupils more confident as learners than before?*  
*What was the impact of the RME-based geometry course on the pupils' performance and achievement?*

The learning outcomes in this study consisted of pupils' achievement and reasoning, pupils' motivation, activity, and creativity. In RME pupils learn mathematics based on activities they experience in their daily life; pupils have a big opportunity to construct their knowledge by themselves, etc. These conditions led to a hypothesis that the RME-based geometry course would increase pupils' achievement. Moreover, in solving a contextual problem pupils are always stimulated (written in the teacher guide) to explain "*what do they do and why?*" This requirement was assumed to have potential to promote pupils' reasoning. Research activities in the assessment stage are summarized in Table 4.

*Table 4: The summary of evaluation of final version*

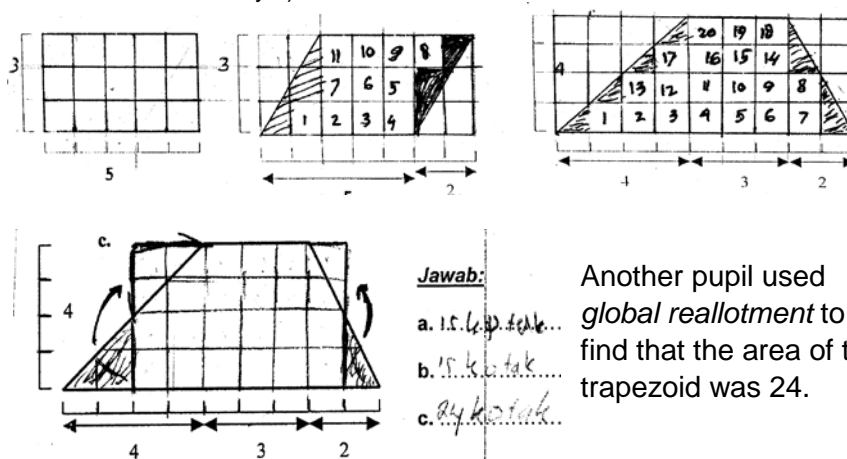
<b>Focus of evaluation (What?)</b>	<b>The purposes of evaluation (Why?)</b>	<b>Evaluation activities (Method (How?))</b>	<b>Instruments</b>
Practicality of the RME-based geometry course (continued).	To gain more insight into whether the learning and teaching process using the RME-based geometry course meet the criteria.	Interview with teachers and pupils, and classroom observations in five schools.	Interview guidelines, observation scheme.
Effectiveness of the RME-based geometry course.	To gain more insight regarding the impact of the RME-based geometry course on the pupils for each level of effectiveness.	Interview with teachers and pupils, classroom observations, pre-test and post-test, and analyzing pupil's portfolios.	Interview guidelines, observation scheme, test and assessment materials, and questionnaire.
Teachers ability to implement the Geometry course-based RME.	To gain information as to whether the teachers could implement the RME-based geometry course as intended.	Classroom observation and interviews with teachers.	Observation scheme, interview guideline.

As mentioned before, the final version of the RME-based geometry course (comprising 10 lesson periods, one lesson takes 70 minutes) was implemented in five primary schools (involving five teachers and seven classes). The results of the assessment stage can be summarized as follows (see also Fauzan 2002):

1. The pupils could use the student book without any difficulties and they could learn the topic Area and Perimeter as intended according to the RME point of view. The teacher guide was useful for the teachers in implementing the RME-based geometry course. Three teachers

said that the teacher guide was easy to use, while one teacher suggested that the teacher guide should be elaborated in more detail (*note*: she used to teach lower grades pupils before). From these findings it can be concluded that the RME-based geometry course met the criteria of the practicality. The practical RME-based geometry course can be characterized as follows:

- The RME-based geometry course had the potential to develop pupils' understanding, reasoning, activity, creativity and motivation in learning the topic Area and Perimeter. These results can be seen on the example of pupils' works below, when finding the areas of rectangle, parallelogram, and trapezoid using their own ideas (the pupils did not know the formulas yet).



Another pupil used *global reallocation* to find that the area of the trapezoid was 24.

The results on the first row show that the pupils used combination of counting and reallocation strategies to find the areas. On the second row, the pupil used global reallocation first, then used counting strategy. There are two important findings showed in the example. The first, the hypothetical learning trajectory worked well (the context used by the pupils to find various strategies). The second, the RME-based geometry course had stimulated pupils' creativity and reasoning in finding the area of a shape.

- The teaching learning process using the RME-based geometry course fostered pupil-centered learning.
- The pupils could use the student book without any difficulties, and they could also learn the topic Area and Perimeter (using the student book) as intended according to the RME point of view.
- The teacher guide was useful for and easy to use by the teachers.
- The RME-based geometry course met the criteria of *the effectiveness* as it resulted in some positive impacts on the pupils. The positive impacts of the RME-based geometry course on the pupils are characterized as follows:
  - The pupils liked the RME-based geometry course. They said that the RME-based geometry course was useful and gave them more confidence as the learners.
  - Most pupils acquired the intended RME knowledge which then enabled them to find out for themselves several concepts included in the RME-based geometry course. They could also use the new knowledge and skills that they had acquired from one lesson in the next lessons.
  - The pupils' attitudes in learning mathematics developed in a positive direction. The pupils became less dependent and did engage actively in the learning and teaching processes. They also became more motivated to find different strategies in solving the contextual problems. Their reasoning developed from being very

- weak at the beginning to being able to reason mathematically by the end of the classroom experiments.
- The pupils actively engaged in the learning process and they also creatively found various solutions in solving the contextual problems in the student book.
  - The pupils' achievements (in the experimental classes) in the post-tests were significantly higher than those in the pre-tests. The pupils' achievements in the experimental classrooms were significantly higher than the achievements of the pupils in Grade 4 and 5 who had been taught the topic Area and Perimeter using the traditional method.
  - A significant difference was found between the motivation of the pupils before and after they had been taught the RME-based geometry course, especially on the aspect *self-concept of mathematical ability* (see Blöte, 1993)
2. The teachers liked the RME-based geometry course, and in general they could implement the Geometry course-based RME as intended, although sometimes they still used the traditional way of teaching. It was also observed that at some occasions the teachers could not fully apply the RME knowledge and skills that they had gained from the training probably because they were not yet used to the RME approach.

## 5. Conclusion

After a four-year study of the development and implementation of the RME-based geometry course at Grade 4 in Indonesian primary schools using design research approach, some conclusions can be drawn (see also Fauzan, 2002):

- a. The RME-based geometry course for pupils at Grade 4 in Indonesian primary schools met the criteria of validity (*content and construct validity*), *practicality*, and *effectiveness*. It suggests that the learning trajectory designed in the RME-based geometry course can be used as a local instructional theory for learning and teaching the topic Area and Perimeter.
- b. The RME approach could be utilized in Indonesian primary schools. Further, the RME approach could address some problems mentioned earlier in this chapter, especially in changing the classroom climate and providing guidelines in how to develop and implement a good quality course material for teaching mathematics.
- c. The two "schools of thought" of design research that were combined in this study resulted a high quality RME-based geometry course and the local instructional theory aimed for.

The results outlined above indicated that the RME approach could be utilized in Indonesian primary schools. Further, the RME approach could address some problems mentioned earlier in this chapter, especially in changing the classroom climate and providing guidelines in how to develop and implement a good quality curriculum material for teaching mathematics.

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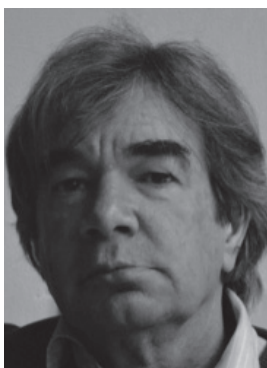
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## Design and Validation of Teaching-learning Sequences: Content-oriented Theories about Transmission of Sound and Biological Evolution

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# 9. Design and validation of teaching-learning sequences: Content-oriented theories about transmission of sound and biological evolution

Anita Wallin & Eva West

## Abstract

*Recent studies indicate that young people in Sweden do not reach the learning goals set within the Swedish science curriculum. Furthermore, many students do not regard their science lessons as particularly interesting or inspiring. Thus, there is a need for improving science teaching and learning in Swedish schools. To meet this challenge we have used a theoretical framework, 'design and validation of teaching-learning sequences', to develop design principles for teaching and learning different science contents. In this chapter we present two case studies, one about sound transmission and one about biological evolution. Our research approach consists of three phases: design, trial and assessment phases. In the design phase we formulate the epistemological differences between the students' prior knowledge and the goals for learning. These differences are called learning demands. They are used to frame the teaching demands which are the foundation of the teaching-learning sequences (TLSs). These TLSs are evaluated in the iterative trial phases, hypothetical design principles are developed and from which the TLSs are redesigned. Results from the assessment phase, together with experiences from previous cycles and research reviews, are used to refine design principles, which are presented as content-oriented theories for teaching and learning.*

## 1. Introduction to the problem

Results from different studies show that Swedish students' learning, interest and motivation in school science are not satisfactory. In both national assessments, NU 2003, (Andersson, Bach, Olander, & Zetterqvist, 2004) and international assessments (PISA, TIMSS) of compulsory school it has been shown that in recent decades Swedish students' results, concerning science knowledge and science skills, have decreased among students in grades 8 and 9 (e.g. Martin, Mullis, Foy, Olson, Erberber, Preuschoff et al., 2008; Swedish National Agency for Education, 2005, 2008, 2010). Notwithstanding that results of assessments should be interpreted with some caution (e.g. Koretz, 2008; Serdar, Sørensen, & Jakobsson, 2011; Sjöberg, 2007), these results indicate that many students do not learn science sufficiently well.

One reason for not learning science might be students' lack of interest and low motivation. Schreiner and Sjöberg (2007) reported from a large-scale international questionnaire, the Relevance of Science Education (ROSE), that Swedish students aged 14-16 considered other school subjects more interesting than science, and students did not value science teaching as particularly inspiring. Moreover, Lindahl (2003) indicates that young students' interest in learning science has implications for their future choices of education. In summary, the quality of science education is important at all levels.

Consequently, there is a need for improved science teaching in Sweden. There are several approaches to the problem. We argue that educational design research (EDR) has the potential to bridge the gap between theory and practice and thereby improve teaching and learning. The reasons are for example that the content is treated at a fine grain size in relation to students' understanding, and the close collaboration with teachers that contributes to teachers' professional development. Our design studies are based on the framework 'design and validation of teaching-learning sequences' (Andersson & Bach, 2005; Andersson, Bach, Hagman, Olander, & Wallin, 2005; Andersson & Wallin, 2006). This framework is inspired of other approaches of EDR (e.g. Kattman, Duit, Gropengieber, & Komorek, 1996; Kelly, 2003; Leach & Scott, 2002; Lijnse, 1994, 1995; Méheut & Psillos, 2004; Tiberghien, 2000).

### Design and validation of teaching-learning sequences

The theoretical framework of 'design and validation of teaching-learning sequences' comprises some general theoretical considerations regarding students' learning. Firstly, the framework is based on a constructivist view of the learner. Secondly, the teacher is considered to be the holder of the scientific knowledge and is well acquainted with common alternative ideas of the teaching content. The teacher's introduction of concepts and systematic planning of situations for the use of concepts is crucial. Thirdly, students should be given opportunities to conceptualise the school-scientific content by means of talking and writing science, writing individual and group reports, and contributing to dialogues, cross-discussions and small-group work. Moreover, the framework emphasizes formative evaluation of students' progress and from this the teaching-learning sequences (TLSs) should be developed consciously and systematically. Beyond that, in this framework students' interest and motivation are continuously in focus. These general considerations together with aspects about the nature of science limited to school science and content-specific aspects limited to the given topic are elaborated into hypothetical design principles.

The point of departure in developing TLSs is previous research, the actual students' prior knowledge and goals for learning a specific content. This design phase is followed by a trial phase in which the sequence is implemented into practice and evaluated. The results obtained are used to improve the design (Figure 1).

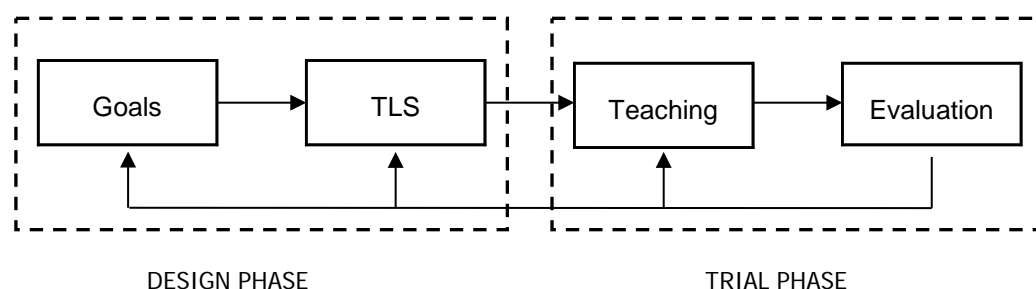


Figure 1: The iterative, cyclic process of design and trial phases (Andersson & Bach, 2004, p. 3)

Two research-based TLSs were designed for two school-scientific areas. In case 1, it was sound, hearing and auditory health for primary and lower secondary school (grades 4, 7 and 8), and in case 2, it was biological evolution for upper secondary school (grade 11). These sequences were elaborated in close collaboration with the teachers involved and they used the TLSs as a resource for their own teaching. In this way, the TLSs were tested, research results from practice were collected and evaluated, and the TLSs were refined.

This process was repeated several times. Accordingly, this iterative process continues until 'a satisfying balance between ideals ("the intended") and realization has been achieved' (Plomp, chapter 1, p. 17). This is the point of departure for our assessment phase.

The contributions from our tradition within educational design research are firstly theoretical contributions by developing content-specific didactic knowledge and secondly by pragmatic contributions to teaching practice by bridging the gap between theory and practice. McKenney, Nieveen and Van den Akker (2006) highlight a third contribution that embraces professional development of all participants, both teachers and researches, involved in the project. This third contribution was also experienced during our case studies, but it is not a focus in this chapter. The content-specific didactic knowledge in our studies is presented as content oriented theories for teaching and learning. Such a theory consists of three categories of design principles: content specific principles, principles concerning the nature of science and general principles. Accordingly, our case studies aim at generating and validating theories for teaching and learning, and thus they can be considered validation studies. The TLSs are of course the main contribution for practice, beyond which they can be extended to a teachers' guide that provide teachers other than those involved in the research with a knowledge base and materials for teaching.

In this book there are other chapters with case studies that aim to develop content- (domain-, topic-) specific theories in different areas of natural sciences, for example macro-micro thinking in chemistry (Meijer, Bulte, & Pilot, 2013), climate change (Niebert & Gropengiesser, 2013) and behavioural biology (Van Moolenbroek & Boersma, 2013).

### **Research questions**

The overall purpose of our case studies is to produce design principles by investigating how students develop an understanding of specific contents of school science as a result of teaching. The specific contents in the two case studies presented here emanate from the school-scientific theories of sound transmission (Case 1) and biological evolution (Case 2). Taking students' preconceptions as the starting point TLSs are designed with the aim that students shall learn the content in such a way that it becomes an intellectual tool. In other words they shall be able to describe, understand, explain, and partly predict phenomena from a more scientific point of view.

Therefore, in this chapter the following research questions are addressed:

1. What are students' understanding of the intended content before, during and after research-based teaching?
2. To what extent do students generalise a school-scientific theory between different contexts?
3. What are the characteristics of a content-oriented theory for teaching and learning?

Design research generally comprises of a number of stages: preliminary research, prototyping phase and assessment phase (see Plomp, Volume A). The content of preliminary research consists of for example a theoretical framework, which is included in this section, and review of literature which will be presented in the next section. The prototyping phase, consisting of iterations of improving and refining the TLSs, are covered by our design and trial phases in section 2 and 3, respectively. The assessment phase in section 4 answers research questions, 1 and 2, and in section 5 (content-oriented theories) research question 3 is elaborated. Finally, in section 6 we add some reflections concerning our work.

## 2. Design phase

As already explained in the first section there are many different components involved which together make the design phase complex. The point of departure is to identify the goals for learning related to the current curriculum, and of decisive importance is to analyse findings from previous research about students' preconceptions of the intended content. Below we present a short literature review of preconceptions concerning the two case studies.

### **Conceptions of sound transmission (case 1)**

Several researchers (e.g. Caleon & Subramaniam, 2010; Eshach & Schwartz, 2006; Fazio, Guastella, Sperandeo-Mineo, & Tarantino, 2008; Houle & Barnett, 2008; Wittman, Steinberg, & Redish, 2003) have reported that students, ranging from 6 years to university age, tend to attribute material properties to sound. In these studies, various ways of describing the material properties of sound are identified; at a micro level where sound is a material entity or small things that are moved, or at a macro level where sound is a discrete object-like substance, such as air or wind, which is transported. Considering sound as something material often results in believing that sound can easily pass through a vacuum and that sound needs a free passage through materials. Another idea (e.g. Lautrey & Mazens, 2004; Linder & Erickson, 1989; Mazens & Lautrey, 2003) is that sound can pass through a material if the 'sound material' is harder, thus referring to properties of the materials i.e. the relative strengths of the materials. Confusion about the role of air was found in several studies. Many students believe for example that the presence of air is a prerequisite for transmission of sound even if other media are present (e.g. Caleon & Subramaniam, 2010; Eshach & Schwartz, 2006).

Driver, Squires, Rushworth and Wood-Robinson (1994), and Eshach and Schwartz (2006) recommended teachers to dedicate efforts in scaffolding students' understanding of the medium in which sound propagates. Fazio, Guastella, Sperandeo-Mineo and Tarantino (2008) reported that students who are able to represent mechanisms of transmission through interactions between molecules, or atoms, can modify their reasoning and arrive at the correct scientific solution as a result of teaching.

Generalising sound propagation through different media is a challenge, and students make use of different representations of the propagating sound mechanism depending on the medium in which the sound propagates (Eshach & Schwartz, 2006). In accordance, several researchers argue that there is a need for the students to construct a general theory for sound propagation (Asoko, Leach, & Scott, 1992; Eshach & Schwartz, 2006; Linder, 1992, 1993; Linder & Erickson, 1989).

The term sound wave seems difficult to conceptualise for many students, irrespective of age (e.g. Caleon & Subramaniam, 2010; Eshach & Schwartz, 2006; Linder, 1992; Wittman, et al., 2003). As described above many students understand sound as something material and this interpretation also occurs concerning the concept of sound waves.

In summary, according to previous research of students' understanding, it is important to consider the following content when designing TLS about sound transmission: the non-material properties of sound, the process of sound transmission in different media and the representation of this process.

### **Conceptions of biological evolution (case 2)**

Evolutionary theory is considered to be a cornerstone in the science of biology. This makes the theory of evolution necessary for an appropriate understanding of biology and implies that it should be a central part of biology education. As several studies have shown, many students have problems with understanding this theory. A major reason for these problems might be that its principles may seem counter-intuitive; both in relation to the students' own experiences of biological phenomena and to the everyday language used to explain such phenomena. Another reason might be that this theory explains the development of life itself and this interacts with people's worldviews. Our understanding of the preconceptions of biological evolution was mainly the results of research conducted in the seventies, eighties and nineties.

Past educational studies demonstrated that children have ideas about evolution before any formal education (Deadman & Kelly, 1978; Engel Clough & Wood-Robinson, 1985). These preconceptions are not consistent, in most cases, with biological science. Several studies have shown that students' understandings do not improve much despite being taught the specific content (e.g. Halldén, 1988; Bishop & Anderson, 1990; Bizzo, 1994; Demastres, Settlage, & Good, 1995). Bishop and Anderson noticed that most students have a conception of evolution as a process in which all individuals in a species adapt to the environment through gradual change.

Common among preconceptions are the opinion that the process of evolution is need-driven (e.g. Bishop & Anderson, 1990; Demastes, Good, & Peebles, 1995; Engel Clough & Wood-Robinson, 1985; Settlage, 1994). If the students do not notice that individuals in every population show variation in significant heredity characteristics (intraspecific variation) the students often reason in terms of needs instead of differences in survival and reproduction (Greene, 1990). Several students use adaptation as the driving force in the process of evolution (e.g. Baalmann & Kattman, 2001; Brumby, 1984; Halldén, 1988).

In summary, according to previous research it is important to consider the following conceptions when designing a TLS about biological evolution: intraspecific variation, randomness, adaptation and discussions about natural selection in relation to the common preconceptions of gradual changes and need-driven evolution.

### **Learning and teaching demands**

The above mentioned research studies are crucial for the design phase. They are used as a tool for constructing pre-tests to capture the actual students' preconceptions in order to identify their starting points. They are also used together with curricula and school-scientific content to formulate goals for learning in the present contexts. In case 1, many of the students in the pre-test expressed their understanding of sound transmission through different media by attributing material properties to sound. However, the goals for learning are that students should conceptualise and generalise sound transmission as a process of motion. Thus, there is a difference between the students' prior knowledge and the goals for learning that is designated, learning demand (Leach & Scott, 2002). In case 2, the starting point for several students was considering the process of biological evolution as gradual changes in *all individuals* of a species, a known preconception in the research literature. The main goal for learning, formulated by the teacher in cooperation with the research team, was that the students should understand and be able to use the theory of biological evolution by natural selection. The process of evolution is anchored in the intraspecific variation, where individuals who have advantageous characteristics survive better and reproduce more frequently and therefore these

characteristics become more represented in future generations. Thus, the learning demand is to develop an understanding of the process of evolution as natural selection and abandon gradual changes in all individuals. In summary, the learning demands exemplified by the two cases formulate the epistemological differences between students' starting points and the learning goals.

These learning demands are the basis when formulating teaching demands which are the foundation of the TLSs. The teaching demands are the point of departure when designing the primary TLSs. We will illustrate this with two examples, one from each case. In case 1, the prototype version of the teachers' guide dealt with the students' possibilities to construct a generalised understanding of sound transmission. This was done during practical work where the students experienced sound transmission through different media such as air, water, iron, and glass. In case 2, the teaching demands were concretised together with teachers to form detailed lesson plans. In these lessons special assignments were designed for small group discussions. One such example is challenging students' understanding of the evolutionary process as need-driven. We used these teaching demands as a foundation to formulate hypothetical design principles.

In the subsequent teaching these hypothetical design principles will continuously be reformulated as a result of formative evaluation. Thus, the design of a specific TLS within our framework is based on content- and context-specific principles interconnected with general principles. The aim is to develop these design principles into content-oriented theories for teaching and learning, and this will be done by testing and improving the hypothetical design principles during the trial phases.

### **3. Trial phase**

In the iterative trial phase formative evaluation of the TLSs is of fundamental importance for researchers, as well as for teachers. Naturally, the teachers are crucial in the trial phase. The results from formative evaluation are used for refinement and redesign of the TLSs and also for improvement of the on-going teaching. In this iterative phase the hypothetical design principles are further developed and reformulated.

#### **Teachers and researchers in cooperation**

The cooperation between teachers and researchers is multifaceted, and we will give some examples from our cases. In case 1, in the first iterative cycle there were many teacher participants involved in an in-service teacher-training course about science education. In the final iterative cycle there were seven teachers and their 199 students (grade 4, 7 and 8) from four different primary and lower secondary schools. The use of teachers and students from different grades was motivated by the aim to study how students from different grades can conceptualise the content of sound, hearing and auditory health. In order to develop and compare teaching and learning from different classrooms the research-based teacher's guide was developed as a knowledge base for teachers in compulsory school. As a consequence of the context dependence the teacher's guide could not be designed as a ready-made lesson plan, but as research-based ideas from which the lessons could be designed for the actual classroom. This guide was continuously improved during the different trial phases. The teacher's guide is available in English on the Internet (West, 2008). In case 2, there were two teachers teaching in three separate trials and altogether 79 students (grade 11). They simultaneously worked in upper secondary school and at the university, and this facilitated a close cooperation between teachers and researchers.



The teachers were actively involved in the whole research process and the researcher observed all lessons. Prior to each lesson there was a meeting where we discussed the next lesson in detail. Fundamental to these discussions were our review of previous research, the results from formative evaluation, the students' logbooks, and the actual classroom. After each lesson we performed an evaluation that was formatively used when planning the next lesson. Throughout the trial phase the teachers were provided with research results concerning their own students' performance.

### **Formative evaluation**

Formative evaluation is pivotal to the trial phase, and we have used a range of tools for formative evaluation. Examples of tools are students' logbooks, students' small-group discussions, database-driven Internet problems, observations in classrooms, teachers' diaries, researchers' interviews, and use of pre-, post- and delayed post-tests. These tools have primarily been used in the research process but they have also had a substantial impact on the on-going teaching.

From our case studies we will give examples of how formative evaluation has been used in the trial phases in order to develop our hypothetical design principles and to redesign the TLSs. In case 1 it was noticed that a number of students did not construct any generalised understanding of sound transmission through various media. One reason was that they only linked sound transmission in liquids to water, and therefore use of other liquids (cooking oil and ethanol) was added in the experiments concerning sound transmission when revising the TLS. It also became obvious, from the students' discussions and tests, that the concept of sound wave was not problematized enough from the beginning which resulted in incorrect use among many students. For this reason this concept was explicitly discussed in the following trial phases and more students built their explanations on school-scientific ideas. In case 2 many students used the term 'need' in their reasoning about the evolutionary process. Through different evaluation tools it became obvious that students applied need with different meanings: they expressed that a characteristic was needed for survival otherwise organisms will die, or that organisms develop a characteristic when it is needed. The first meaning is in accordance with biological evolution but the second is not. From this experience, and with consideration to previous research results, we constructed a database Internet driven task with the aim to meet these demands. Our prediction was that the students would answer the task in a more scientific way if they were given specific information about the existing variation in a population, which is not usually given in such tasks. As a result, the students became more inclined to discuss differences in survival and abandoned reasoning about needs, according to our hypothesis.

As we have shown the cooperation between teachers and researchers, together with formative assessment, are crucial for the development of the TLSs in the trial phases. In addition, an in-depth evaluation of students' learning is essential for design research which is the link to the assessment phase.

## **4. Assessment phase**

During the iterative phases we have formatively collected data in order to improve and redesign the TLSs and to develop the hypothetical design principles. In order to refine these we have summatively analysed students' learning in-depth during the assessment phase. The analysis consists of interpreting and categorising the students' answers from a school-scientific perspective. The students' answers were collected by the use of similar items at three occasions; the pre-test, the post-test at the end of the teaching, and the delayed post-test one

year after. The aim of the delayed test was to capture students' long-term learning, and besides this arrangement minimizes the bias of students' memorising the items. In both cases the reliability of the categories were estimated and refined by the use of inter-rater reliability which was measured as per-cent correspondence between the authors and another researcher who separately and independently scored a sample of answers. Finally, the distribution of the categories were analysed statistically in order to compare results from different tests and from different groups of students.

### The theory of sound transmission (case 1)

In case 1 the students' views about sound transmission were investigated by use of their written answers to four items concerning transfer in air, water, wood and vacuum. The analysis involved interpreting students' underlying theories of sound transmission by interweaving each student's answers to all four items. The inter-rater reliability was measured from two independent categorisations of three researchers. The inter-rater reliability was 80% and 85%, respectively. In cases where our views differed, we discussed each case until we agreed. When the students answered the items they either described the transmission of sound as a transfer of matter or as a process of motion or both (Figure 2).

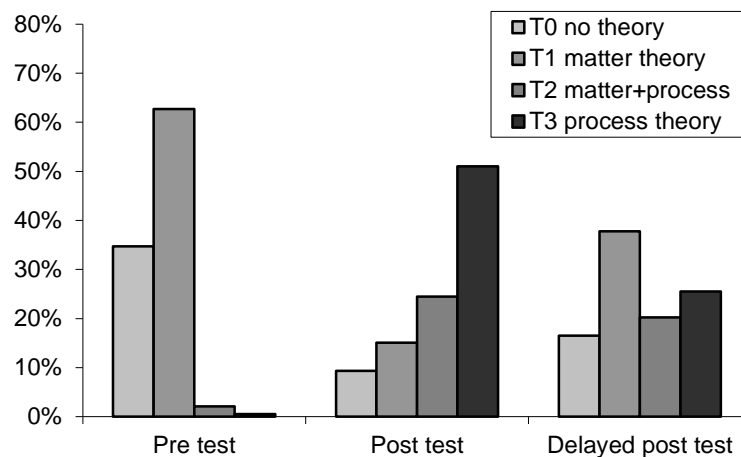


Figure 2: The distribution of students' use of theories of sound transmission. Pre-test ( $n=193$ ), post-test ( $n=192$ ) and delayed post-test ( $n=188$ ). (West & Wallin, 2011, p. 17)

Before the intervention, the answers to the four items from most students showed matter-based ideas (T1) and in the remaining answers almost no theories were identified (T0). However, after the teaching intervention half of the students used process reasoning (T3) and a quarter used a combination of both process and material reasoning (T2). One year later the most common idea was the matter-based one as in pre-test. However, compared to the pre-test more students based their statements on process reasoning (T3). Thus, the results indicate a shift in students' understanding from the use of a theory of matter before the intervention to embracing a theory of process afterwards.

The category T3 represents the students that show signs of having constructed a generalised theory for the transmission of sound; that is they are explicitly using process reasoning in three or four out of four items when explaining sound transfer in relation to air, water, wood and vacuum. In the pre-test almost no student used a generalised theory, but in the post-test 51% of students showed this idea and one year later 26% of the students still applied this theory.

Consequently, teaching and learning the generalised theory of sound transmission might be considered fruitful. However, the results also implicate the importance of recurrent teaching. The results from case-study 1 are previously published (West, 2011b; West & Wallin, 2011). Further results from this study are published in West (2011a; 2012).

**The theory of biological evolution (case 2)**

In case 2 students' performance from three successive design cycles (exp1, exp2, and exp3) was studied by use of answers from open-ended items. In these items the students were expected to use the theory of evolution by natural selection to explain a long term change in a population of cheetahs/seals. The categorisation of the students' answers was performed in two steps. First, two different broad categories of students' answers were distinguished: one with non-scientific ideas and one with scientific ideas. Second, the answers categorised as containing scientific ideas were further analysed for the existence of five different evolutionary components described by Ferrari and Chi (1998). The five components are: random intraspecies variability, heritability, differential survival rate, differential reproduction rate, and accumulation of changes over many generations. An answer with scientific ideas was scored 5-8 depending on the number of components correctly used and an answer with non-scientific ideas was scored 1-4.

The inter-rater reliability was measured from two independent categorisations of two researchers; the correspondence in dividing the answers containing non-scientific respectively scientific ideas was 99%. The correspondence concerning the different components in the answers with scientific ideas were between 89-98%, but after discussions the researchers were able to come into agreement in every case. The results are presented as group mean scores (see Figure 3).

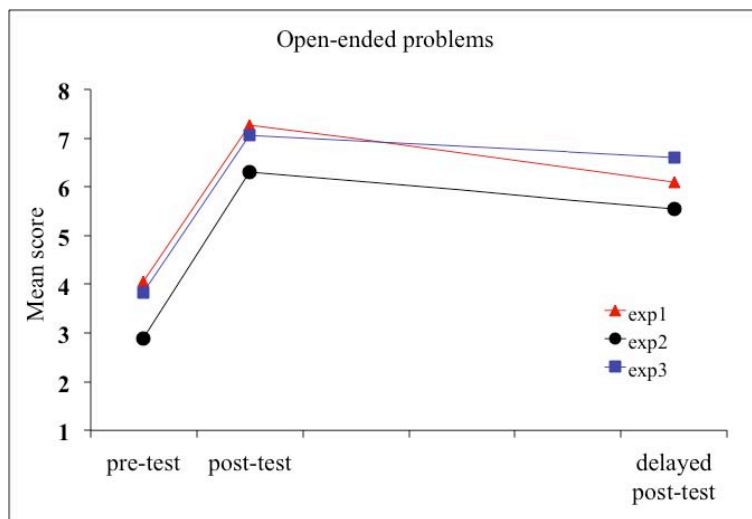


Figure 3: Comparison of group mean scores of the open-ended items between the pre-test, the post-test, and the one-year delayed post-test

The mean scores in the post-test are significantly higher than in the pre-test for all three experiments (Wilcoxon's matched-pairs signed-ranks test;  $p < 0,001^{***}$ ). In exp1 there is a significantly lower mean score in the one-year delayed post-test compared to the post-test, but in exp2 and exp3 there are no significant differences (Wilcoxon's matched-pairs signed-ranks test;  $p(\text{exp1}) < 0,001^{***}$ ;  $p(\text{exp2}) = 0,096$ ;  $p(\text{exp3}) = 0,117$ ).

The students' consistency in using the scientific theory of evolution by natural selection throughout each test (7-8 different items) was analysed by investigating their ability to generalise the theory through the different items. From the pre-test to the delayed post-test the number of students who answered the whole test with exclusive scientific ideas increased from 4 to 34 of the 79 students. The criterion for the whole test to be categorised as answered by exclusively scientific ideas was that no open-ended and only one of the multiple-choice items was answered unscientifically. In the delayed post-test 75 % of the students answered scientifically on more than half of the items compared to 20 % in the pre-test. These results indicate that a greater proportion of our students reached a scientific understanding compared to several international studies (e.g. Bishop & Anderson, 1990; Bizzo, 1994; Demastres, Settlage, & Good, 1995).

The results from case-study 2 are previously published (Wallin, 2004, 2011).

The assessment phase shows the students' abilities to learn and use school-scientific content. These results were used to develop and define design principles, which will be summarised as content oriented theories in the next section.

## 5. Yield of the project: Content-oriented theories

The final phase in our design-research tradition is to formulate design principles in the form of content-oriented theories for teaching and learning. They emanate from the results of case studies, previous research results, results from the iterative research cycles preceding the final cycles and systematic national and international surveys (Figure 4).

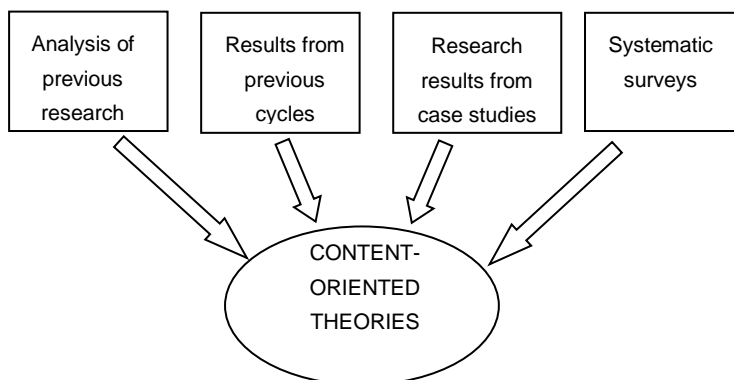


Figure 4: Construction of design principles in the form of content-oriented theories

According to the framework of 'design and validation of teaching-learning sequences' content-oriented theories are composed of three different categories of design principles:

- content-specific design principles,
- design principles concerning the nature of science, and
- general design principles.

As shown in our cases different fields of school science has its own, unique content-specific design principles. We will below present the content-specific design principles related to our two case studies.

### **Content-specific design principles**

In case 1, if the following content-specific design principles are considered in teaching, the students' opportunities to learn and understand the school-scientific theory of sound and sound transmission will be improved:

1. Sound arises when objects vibrate, irrespective of which object is causing the sound.
2. The movement of a vibrating object in air is transmitted via particles in the air. Every movement from a single air particle is transferred to the air particle nearby in an interaction.
3. The movement of vibrating objects is transmitted in gaseous, liquid and solid substances via the particles in these substances. The movement of each particle is transmitted to the particle nearby in an interaction.
4. The closer the particles, the faster the transfer of sound.
5. Different ways of representing sound transmission need to be problematized in teaching.
6. Sound transmission is an emergent process (large-scale process whose motion differs from the motion of the constituent particles).
7. Sound transmission is a complex, emergent process (influenced by elastic and inertial properties).

In case 2, if the following content-specific design principles are considered in teaching, the students' opportunity to learn and understand the school-scientific theory of evolution and its consequences will be improved (i.e. understanding the theory of evolution means being able to actually use the theory to describe, understand, explain, and partly predict biological phenomena):

1. Evolutionary time is made concrete, and different hypotheses about the origin of life are discussed.
2. Instruction about the theory of evolution is divided into two processes - origin of hereditary variation and natural selection.
3. It is stressed that only the process first mentioned is random and that the second is of necessity a consequence of the variation meeting the environment.
4. Existing variation in populations is discussed. Genetics is introduced to get an idea of how differences and similarities come into existence. Knowledge about the existing variation in hereditary characteristics is regarded as a necessary platform for proceeding to natural selection, thereby building up an alternative to ideas of evolution caused by need, effort, will, etc.
5. Natural selection is divided into two parts:
  - differential survival rate, and
  - differential reproductive rate.
6. It is made clear that differences in survival are not enough to explain evolutionary changes. The crucial factor is differences in reproductive success.
7. Accumulation is introduced as a term for the increasing proportion of individuals with a certain hereditary characteristic due to natural selection. After that the evolutionary meaning of adaptation is discussed.
8. The various levels of organisation that are used when discussing evolution are made explicit.
9. The theory of evolution through natural selection is used to explain the development of life, biological diversity, sexual selection, co-evolution, speciation, behavioural ecology, ethology and so on.

### **Design principles concerning the nature of science**

The design principles concerning the nature of science are more or less common for all science teaching. They are previously presented as part of our framework (e.g. Andersson & Bach, 2005; Andersson & Wallin, 2006), and accordingly they have been included in our hypothetical design principles.

The design principles concerning the nature of science are:

1. The nature of science is made explicit.
2. The differences between science and non-science are discussed.
3. The students are invited to participate in the way science explains phenomena in the world. Great respect is shown the students who have alternative ideas about this subject.
4. The students are offered many opportunities to use the theory as an intellectual tool.
5. The teaching is planned and carried out so that the theory stands out as the main unifying thread.
6. Students are given opportunities to reflect on the advantages and limitations of different representations.

### **General design principles**

The general design principles applicable for teaching school-science as well as other school subjects are also included in our hypothetical design principles (e.g. Andersson & Bach, 2005; Andersson & Wallin, 2006).

The general design principles are:

1. The teacher looks upon himself/herself as a representative of the science culture, who introduces concepts, gives scientific explanations, and arranges situations for applications of these concepts.
2. The teacher is well acquainted with common alternative ideas of the teaching content and is aware of these during teaching. He/she is attentive to and interested in the students' ideas, both those already known through the literature and new ones.
3. The teacher creates a permissive classroom climate in which the students can share and discuss their ideas and reflections in a positive way.
4. A fair amount of time is used for discussing and solving problems involving the students in having to apply the teaching content in different situations. The students are given opportunities to take their stands in questions concerning everyday and environmental issues including formulating arguments.
5. Extensive time is used to discuss and solve concrete problems, which make the students familiar in using the taught content.
6. Deep learning is encouraged.
7. Formative evaluation is used by both students and teachers.
8. The students' interest and motivation are crucial and therefore continuously must be stimulated to be maintained.

We have listed the different design principles: content-specific, nature of science, and general, to make the presentation of our theory coherent and hopefully usable in practice.

Content-oriented theories from our research-group are previously published in Andersson and Bach (2005), Andersson and Wallin (2006), Wallin (2004) and West (2011b).

## **6. Reflections**

Outcomes from the field of education are always diverse and difficult to measure with accuracy (Hammersley, 2009). Thus, there are limitations related to design-research such as "design-based researchers are not simply observing interactions but are actually 'causing' the very

same interactions they are making claims about" (Barab & Squire, 2004, p. 9). Our studies have complex designs and they are relatively small scale, and therefore no statistical generalisations are possible to draw from our cases to population. Nevertheless, "if the details are sufficient and appropriate for a teacher working in a similar situation to relate his decision making to that described" (Bassey, 1981, p.85), then the results can be useful for other designers as well as teachers. In addition, the content-oriented theories developed from case studies from various contexts might be possible to generalise in that they give guidance and directions for further design studies. This is what Yin (2009, p. 38) refer to as 'analytic generalization'. The generalisability in design research is further discussed in the first chapter of this book (Plomp, p. 21).

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## Design Research as an Inquiry into Students' Argumentation and Justification: Focusing on the Design of Intervention

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# 10. Design research as an inquiry into students' argumentation and justification: focusing on the design of intervention

Oh Nam Kwon, Mi-Kyung Ju, Rae Young Kim, Jee Hyun Park & Jung Sook Park

## Abstract

*In this chapter, we describe the didactical mechanisms of an instructional design that contributes to the improvement of students' mathematical power. Specifically, we provide a detailed description of the processes through which instructional mechanisms - namely instructional tasks, classroom interaction, and teacher's discursive role - evolved through an instructional intervention. Based on the theories of Realistic Mathematics Education, we analyzed a case of an eighth-grade inquiry-oriented mathematics classroom in Seoul, Korea, focusing on the methodological aspects of Educational Design Research (EDR) as well as its practical implications. Specifically, we discuss how EDR that helped us construct a theory about students' mathematical argumentation and justification, describe their developmental trajectories in the context of inquiry-oriented mathematics lessons, and the didactical mechanisms that promoted this transformation. We also discuss how EDR contributes to the development of teacher professionalization.*

## 1. Introduction

Mathematical empowerment has been one of key issues in mathematics education since the 1990s. The *Curriculum and Evaluation Standards for School Mathematics* released by the National Council for Teacher of Mathematics (NCTM) in 1989 espoused the development of mathematical power for all students as the goal of school mathematics. In this document, mathematical power is conceptualized as "an individual's abilities to explore, conjecture, and reason logically, as well as the ability to use a variety of mathematical methods effectively to solve non-routine problems" (NCTM, 1989, p.5). This notion of "mathematical power" is based on the recognition that mathematics is a human activity of exploring the world and communicating one's mathematical ideas. From this perspective, a mathematics classroom is considered as community of mathematical practice where all students are engaged in constructing mathematics through reasoning, conjecturing, verifying, justifying, inventing, problem solving, and communicating mathematically. The Korean national curriculum of mathematics has shared this perspective on mathematical empowerment to include mathematical problem solving, inferential reasoning and communication as key competencies in school mathematics education (KMEST, 2011). This trend suggests that both the curriculum and daily educational practice of school mathematics require significant restructuring to provide more room for students' active agency and authorship that is essential for mathematical empowerment.

While Korean mathematics educators share the international vision of mathematics education for empowerment, they encounter the issue of educational reform in the specific context of Korean school mathematics. Korean students have been ranked as one of the highest achievement in Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA).

However, their achievement in the tasks demanding higher order cognitive function is relatively low compared to their achievement in the tasks requiring procedural, skills (Kim, Kim, Kim, & Park, 2008; Na, 2006). Also, it has been shown that Korean students have developed attitudes toward mathematics that are detrimental to their mathematics learning (Kim et al., 2008). In response to these challenges, the Korean Minister of Education, Science, and Technology (MEST) has recommended in the development of national mathematics curriculum to emphasize the higher order cognitive abilities and mathematical dispositions to seek, evaluate, and use quantitative and spatial information in solving problems and in making decisions. It also highlights the importance of designing a learning environment that enhances students' intellectual autonomy and active agency in the learning of mathematics (MEST, 2011).

In this context, our research team developed a model of inquiry-oriented instruction based on Realistic Mathematics Education (RME). RME is based on the didactical phenomenology of Freudenthal (1986; 1991) explaining mathematics as a product of human activity. From this perspective, teaching and learning of mathematics should take its point of departure in mathematics as an activity instead of mathematics as a ready-made-system. For the development, we adapted educational design research (EDR) as a research methodology and collaborated with a teacher in the development and implementation of the developed instruction. The teacher was a graduate student majoring in mathematics education. In this chapter, we will restructure her master's thesis (Kim, 2006) assessing the effect of the inquiry-oriented mathematics instruction upon students' mathematical argumentation and justification from a methodological point of view. We do this in order to describe the process of how EDR contributes to the construction of a grounded theory concerning students' mathematical argumentation and justification in an authentic context of mathematical inquiry.

Thus, in this chapter, our research focuses on the following two questions: first, how does EDR provide researchers with a lens for investigating students' mathematical argumentation and justification in order to construct relevant theory for those mathematical competencies? Second, how does EDR contribute to identifying more effective and relevant instructional intervention for students' mathematical empowerment? To address these questions, we will present a description of the process through which students' mathematical argumentation and justification became transformed in the context of inquiry-oriented mathematics lessons. The description includes not only which patterns of mathematical argumentation and justification emerged but also which didactical mechanism promotes the transformation of mathematical argumentation and justification. Based on the description, we will discuss the methodological aspects of EDR that had contributed to theory-construction and the development of an effective instructional intervention model.

## **2. Development of conceptual framework**

In this section, we present how we conducted our design research for inquiry-oriented mathematics class. We begin with how we formulated a local instructional theory concerning mathematical argumentation and justification. We also introduce a theory for designing an instructional intervention for our inquiry-oriented mathematics class and then discuss how we placed the experiment in a theoretical context for retrospective analysis.

### **The principles of intervention**

As mentioned before, we adapted the theory of Realistic Mathematics Education (RME) for the development of our inquiry-oriented instruction model (Freudenthal, 1986, 1991). In RME, mathematics is considered a human activity rather than fixed system of ready-made knowledge.



Thus, instead of passively receiving mathematics as given, it is recommended that students be given opportunity to reinvent mathematics through actively conducting inquiry into a mathematical context problem (Gravemeijer & Doorman, 1999). Therefore, progressive mathematization through guided reinvention is the primary instructional design heuristic in RME. According to the principle of guided reinvention, an instructional design should allow students to conduct mathematical inquiry to actively construct the mathematics intended by a curriculum through the interaction with a teacher (Gravemeijer, 1999). By adapting RME, our inquiry-oriented mathematics instruction was designed to provide an environment where students were encouraged to actively participate in an investigation of a mathematical context for constructing mathematics through progressive mathematization. In addition, students were encouraged to negotiate their mathematical ideas to develop a shared mathematical meaning. Through this process of explicit negotiation, the inquiry-oriented mathematics instruction led students to the reinvention of mathematics (Rasmussen & Kwon, 2007).

There are three principal facets in the design of our inquiry-oriented mathematics instruction to promote students' active agency and authorship in mathematics learning. First, learning should start from contexts that are experientially realistic for students. Thus, tasks were not only embedded within the disciplinary system of mathematics but also within students' mathematical experience. Second, tasks asked not only a specific solution of a problem but rather encourage students to analyze the context of given tasks, develop explanation and justification, and ultimately to invent principal ideas behind the problem context. Based on the inquiry of the contexts, students' informal mathematical ideas were progressively transformed into formal mathematics. Lastly, it is important to note that the process of progressive mathematization was facilitated in the context of social interaction among teachers and students. In the inquiry-oriented mathematics class, teachers and students played roles that are different from the roles they assume in traditional lecture-style mathematics classes. Instead of working on a given task individually, students worked collaboratively in mathematical inquiry. In the collaborative inquiry, students also shared their mathematical meanings together and collectively constructed mathematics. Teachers were recommended to build on students' mathematical reasoning and to guide their reinvention of mathematics by locating instructional starting points that are experientially realistic to students and help integrate students' mathematical understanding into the classroom practice of mathematics.

### **Argumentation and mathematical justification**

While there is no one clear-cut definition of what argumentation is, argumentation is broadly characterized as what convinces another person (Perelman, 1970, recited from Reid & Knipping, 2010). Kreumheuer (2007) conceptualizes argumentation as a process leading to the verification of a statement. Wood (1999) defines an argument as a discursive exchange among participants for the purpose of convincing others through the use of certain modes of thought, and argumentation as an interactive process of knowing how and when to participate in the exchange. While argumentation is often conceived as activity that coincides with proof or justification, argumentation is a broader notion and is regarded as an essential part of learning mathematics (Kreumheuer, 2007; Staples, Bartlo, & Thanheiser, 2012).

In the analysis of argumentation, Toulmin's patterns of argumentation are most often adapted. Toulmin (1958, 2003) offered the skeleton of a pattern for analyzing arguments that consists of six components: data (D), claim (C), warrant (W), backing (B), qualifier (Q), and rebuttal (R).

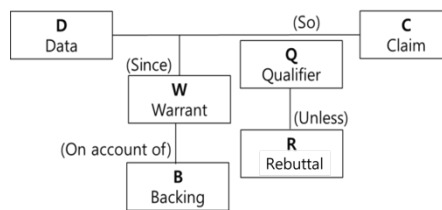


Figure 1: Revised argumentation scheme (Toulmin, 2003)

Van Eemeren and Grootendorst (1992) identify four types of argumentation structures according to the relationship between a claim and a warrant. “Single argumentation structure” includes one claim and one warrant. Although a single argumentation structure is the simplest structure of argumentation, it rarely makes up argumentation. “Multiple argumentation structure” includes more than one warrant to support one claim. “Compound argumentation structure” contains various warrants for a claim that interact so as to make the claim a springboard for deriving a new claim.

In our research, argumentation is considered as a valid unit of analysis to approach the questions of how learning progresses in a mathematics classroom and how students become intellectually autonomous and mathematically empowered in the context of mathematics practice in class (Yackel & Cobb, 1996). In particular, our analysis focused on students’ justification by using Toulmin’s skeleton of a pattern for analyzing arguments. Recent documents of mathematics education emphasize justification as one of key competences in mathematics not only because of its significance as a disciplinary practice but rather because of its role as a learning practice (Cohen & Ball, 2001). As a learning practice, justification provides students with an opportunity to reflect upon their own mathematical idea and enhance their understanding of mathematics (Boaler & Staples, 2008; Wood, Williams, & McNeal, 2006). In this regard, a deeper understanding of students’ justification is critical in realizing the current visions of reform for students’ mathematical empowerment that increasingly emphasizes mathematical justification in the teaching and learning of mathematics.

### Placing the experiment in a theoretical context and retrospective analysis

In the previous section, we presented the instructional theory that frames our educational goals and the instructional methods for our intended classroom design experiment. We consider that the strengths of EDR to our goal lie in the design-analysis-redesign cycle which involves testing and refining educational theories in context as capturing the specifics of practice and creates the conditions for developing evidence-based knowledge relevant to resolving complex issues that teachers and researchers confront in real classrooms (Anderson & Shattuck, 2012; Brown, 1992; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). Thus, after we formulated a theoretical model of inquiry-oriented instruction, we actually conducted the design experiment in class. The process of the design experiment consisted of micro cycles of design and analysis. During the implementation of the instructional activities, we collected and analyzed data of students’ mathematical argumentation and justification. Based on the analysis, we revised specific aspects of the instructional design. Finally, after the design experiment was completed, the researchers conducted retrospective analyses on the entire data, including video-recordings of all classroom lessons, copies of all the students’ written work, field notes, and audio-recordings of the daily debriefing sessions during the design experiment.

### 3. Design and development phase

The overarching goal of this study is not to confirm our hypothetical learning trajectories, i.e. expected learning process through mathematical tasks to achieve learning goals (Simon, 1995), but rather, to investigate both how EDR as a research method helped us to see the transformation of students' argumentation and justification through an inquiry-oriented mathematics course, and how EDR as an instructional design promoted students' argumentation and justification. For this purpose, after the starting points and instructional endpoints were specified by diagnostic assessment and theoretical reflection that we described in the previous section, we started with our discussion of the process of designing the research by considering the design of the intervention and types of data we might collect and analyze to address our research questions. Our research was conducted with 16 eighth-grade students in an inquiry-oriented mathematics classroom, and the content focus was on finding and generalizing patterns. Patterns are one of the topics considered as key to reform mathematics education in algebra.

In this section, we provide more details about the design of this study from preparation to reflection, especially focusing on the intervention (instructional tasks, classroom interaction, and teachers' discursive role) and data collection in the classrooms. The cycles of design and analysis illustrates how EDR played out during intervention and how we collected and analyzed the data through that process.

#### **Design of the intervention**

In order to understand and improve students' argumentation and justification, we developed three types of interventions: instructional tasks, varying degrees of classroom interactions, and teachers' discursive role. In inquiry-oriented mathematics classrooms, students should be able to construct their own mathematics by active participation and negotiation of the meanings with the facilitation of the teachers. According to the reinvention principle of RME, they should have opportunities to create their informal strategies to solve problems in realistic situations and to develop them into formal mathematical practices (Freudenthal, 1973). In our study, we focused on the kinds of instructional tasks that could help students develop their argumentation and justification in inquiry-oriented mathematics classrooms, the types of interactions could facilitate students' participation, and the kinds of roles teachers should play in the classrooms to facilitate that process. In what follows, we discuss these three aspects in more detail.

#### ***The instructional tasks***

The instructional tasks for the class sessions were developed on the basis of *Mathematics in Context* (MiC) reflecting the ideas of RME. Since guided reinvention from the progressive mathematization of RME is the conceptual foundation in our design, the tasks were designed and organized to help students not only devise their informal strategies for solving problems in various realistic situations but also develop those strategies into more formal approaches applicable to other situations. Starting with informal strategies to discover geometric patterns from numbers, the tasks were arranged to help students explore more complex patterns in real contexts such as stacked cans and ping-pong games, generate new patterns, find formulae to explain the situations, and formulate new formulae to generalize the patterns.

#### ***Classroom interaction***

Regarding mathematics as a collective activity, we wanted to investigate how students' argumentation and justification could improve in different interactive situations. As mentioned in the previous chapter, students' active agency and authorship are crucial for mathematical

empowerment. It is thus important to provide students with opportunities to engage with mathematical inquiry as active agents. When Freudenthal (1983) conducted 'phenomenological didactical analyses' to discover which problems and activities could help students identify important mathematical concepts and structure, he found that inter-colleague deliberation including discussions with teachers and communication with other students could be useful to understand what would be important to establish a model, and in what ways situation-specific solutions could be produced.

Under the assumption that mathematics is a social practice, mathematics classroom is a community of mathematics practice. Teaching and learning is a daily practice for the collective construction of mathematics. Thus, in order to support the participation of students as active agents of the construction, we provided opportunities to experience different types of interaction among them: individual learning, small group discussion, and whole class discussion. We decided to organize the three different types of interaction in the form of a mini-cycle so as to examine how these different types of interaction might be related to the improvement of students' argumentation and justification.

### ***Teachers' discursive role***

Considering that the mathematics classroom is a community of learning where students can construct their own knowledge, students' active engagement with mathematics through classroom discourse may lead to the development of students' competencies and identities. From this perspective, teachers' discursive role becomes important to help students engage in thoughtful and sustained classroom discourse as active participants and agents. Since mathematics discourse may be a defining feature of the quality of classroom experience, teachers should focus on providing every student with opportunities to share his or her ideas and support other's ideas, and scaffolding student engagement to develop and orchestrate a sustained community (Walshaw & Anthony, 2008).

In particular, teachers' scaffolding argumentation practices are very important to shape students' mathematical justification and argumentation. Teachers' instructional scaffolding such as encouraging students to elaborate an idea, asking them to make their ideas explicit, and challenging students' claims by using counterexamples can help students understand their ideas more deeply (Morrone et al., 2004). Stein et al. (1996) identified that such teachers' sustained efforts were the main contributing factor to support students' justification and explanations. In fact, many students do not know how to engage with the discourse including how to make arguments, how to negotiate their meanings, and how to justify their arguments (Woodward & Irwin, 2005). Thus, teachers' instructional scaffolding can facilitate a robust community of learning and help students develop their mathematical thinking and skills.

In this vein, questioning can be seen as one of the most useful ways to develop students' mathematical thinking (Vacc, 1993). Purposeful questioning can help establish a learning community where students can elaborate their thinking collaboratively and encourage students to connect among different ideas (Manouchehri & Enderson, 1999). Although we could not make a list of specific questions to ask in advance because questions are context-sensitive, we could develop the ideas of what and how to ask questions through intensive discussions after each session.

### Data collection

With the design of the intervention, we also considered what kinds of data we needed to collect and how to analyze the data to answer the research questions. In particular, we focused on how to document the changes in the students' argumentation and justification as well as the ways in which these changes were supported in the inquiry-oriented mathematics classroom.

Ten 90 minute-sessions on finding and generalizing patterns were conducted during a semester. Six out of the ten were, however, introduced and analyzed in this chapter to give a closer look into what we found from this study. The four lessons excluded from this study since they consisted of assessments such as diagnostic and summative assessments. Therefore, the remaining six consecutive lessons are enough to see the dynamics of design research. Table 1 shows the tasks used in each session and stages emerged from the analysis based on the systematic theory of argumentation by van Eemeren and Grootendorst (1992). More details will be provided in the next section.

*Table 1: The instructional tasks and stages emerged from the analysis*

Sessions	The Title of the Task	Content	Stages
1	Pipes	<ul style="list-style-type: none"> <li>• Diagnostic assessment</li> <li>• Exercise</li> </ul>	
2	Triangular numbers & Square numbers	<ul style="list-style-type: none"> <li>• Finding out geometric patterns from triangular and square numbers</li> </ul>	Stage1: Single argumentation
3	Cans	<ul style="list-style-type: none"> <li>• Finding patterns in more complex geometric representations and generating new patterns</li> </ul>	Stage2: Multiple argumentation
4	Ping-pong	<ul style="list-style-type: none"> <li>• Finding patterns in the context of the problem and generating formulae</li> </ul>	
5	Shapes of V and W	<ul style="list-style-type: none"> <li>• Understanding the formula to explain the context of the problem</li> </ul>	Stage3: Compound argumentation
6	Shapes of V and W	<ul style="list-style-type: none"> <li>• Understanding the formula and generating a new formula</li> </ul>	

In order to investigate how students' argumentation and justification changed across sessions, the primary investigator who was the teacher of the class video- and audio-recorded all the classroom sessions as well as the discussions in the target group of the students. She also transcribed all of the utterances of the teacher and students during the classes. She conducted individual semi-structured pre- and post- interviews with the students to examine what they thought about each session of the class and what they learned from the class.

We also collected and analyzed a copy of the students' work to explore how students solved the problem and developed their ideas across the sessions. These data were analyzed not only to examine which didactical mechanisms improved students' argumentation and justification but also as the basis of our reflection which helped us revise the intervention for the next session. We analyzed all the data based on argumentation theories from Toulmin (2003) and Van Eemeren and Grootendorst (1992) described in the previous section.

### **Cycles of design and analysis**

One of the main characteristics of EDR is its focus on iterative design that evolves over time. Based on the aforementioned conceptual foundations, we designed the intervention and conducted the design experiment. We found some problems or issues from the implementation and discussed how to redesign the study. Design-analysis-redesign cycles were used across this study, which allowed us to find a way of supporting student learning.

As shown in Figure 2, although this process seemed to be repeated, the cycles evolved as students' argumentation and mathematical justification improved along with the development of intervention. In particular, one of the main characteristics of this study is the multilayered cycles of the study in terms of intervention (Gravemeijer & Cobb, 2006). In this chapter, we focus on the micro-cycles (indicated as the black cycles) of the second macro-cycle, which were based on the results from the first macro-cycle. After the first macro-cycle, which ended one year before the second one, we assessed the whole study including the evaluation of the intervention and students' reactions to the intervention, and incorporated what we learned in the intervention in the second macro-cycle.

Similarly, within a micro-cycle, although we outlined the instructional tasks in advance, we revised the tasks after each session to meet students' needs and reflect what we had learned about students' thinking and understanding from each session. For example, after the second session, we found that students were likely to not explain the patterns because they felt that they were visually obvious. We revised the task into the "cans" task that students could not get a triangular number simply by applying the formula. By doing so, we expected that this task used in session 3 could help students recognize the importance of mathematical meanings of a formula in problem solving. Like this, we reorganized the tasks by considering the order and difficulty levels of the tasks as well as the students' responses to the tasks. We either eliminated or added some content if necessary and applied it to the next class. The criteria charged in the process were relevance, consistency, practicality, and effectiveness (Nieveen, 2009): Were the tasks relevant to the students' needs and their level of understanding? Were the tasks logically associated with each other? Were the tasks appropriate to use in the school settings? Were the tasks useful to see the relationship between argumentation and mathematical justification?

It was critical for researchers to reflect and share what they found from the class. Engaging in such formative evaluation along with the whole process of research was a significant learning experience for all researchers, who range from mathematics teachers in secondary schools to mathematics teacher educators. This process was beneficial not only to reconstruct the rationales for particular design decisions, such as the underlying design principles and the intervention, but also served to enhance the researcher's professional knowledge and skills in the design of instructional activities and evaluation.

Within a set of instructional tasks (usually 2-3 small tasks) in a session, mini-cycles of different types of interactions were given for each task to document the changes in students' argumentation and justification as a function of those interactions.

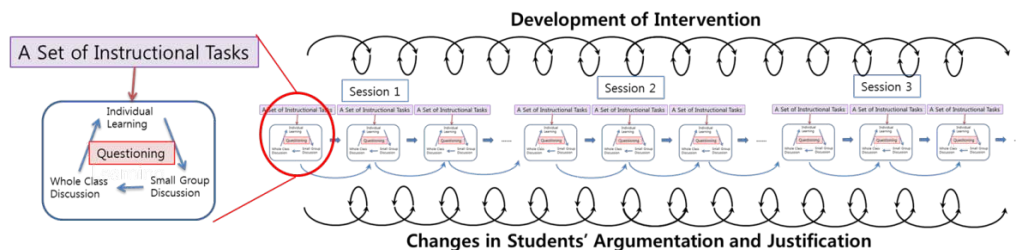


Figure 2: Cycles of design and analysis

#### 4. The development of students' argumentation and justification in relation to the intervention

In this section, we attempt to show how EDR allowed us to explore the process of students' argumentation and justification through the development of intervention and how EDR promotes students' empowerment in relation to the changes of intervention. The three types of argumentation structures emerged through the intervention: single, multiple, and compound. In each argumentation structure, we describe in detail the design process in terms of the changes of intervention and student learning.

##### Stage one: Single argumentation

In stage one, there were two sessions. As the first stage of the inquiry for patterns, the tasks were to find out the patterns of the number of dots in a triangle and square, 'triangular numbers' and 'square numbers' (Figure 3) and to understand the meaning of the formula used to get them. Especially, the goals of the tasks were to prompt students to discover various solutions on their own (for the geometric patterns of the triangular numbers and the square numbers), and to justify their solutions with active argumentation. For example, one of the problems asked to find specific values of the 31<sup>st</sup> and the 29<sup>th</sup> triangular numbers when the 30<sup>th</sup> triangular number was given. The task was presented after the students learned about triangular numbers in the first mini-cycle during the first session. Since the students hadn't been exposed to the inquiry-oriented mathematics instruction, they merely introduced their own solutions in the small group discussion. As a result, their argumentation and justification followed a single argumentation structure without elaborating their mathematical thinking in problem solving (Figure 3).

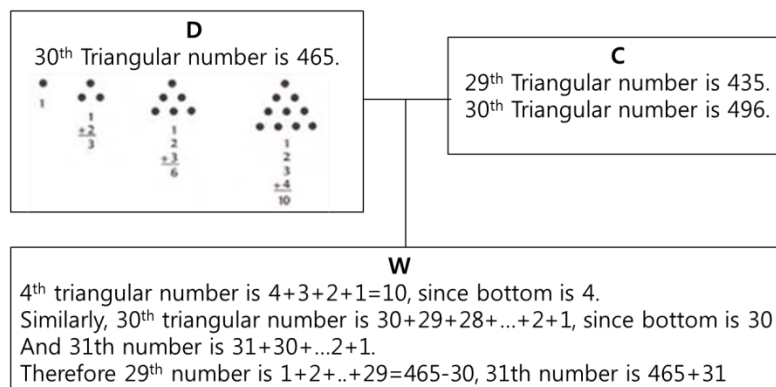


Figure 3: A small-group discussion in session 2

Moreover, although the teacher tried to elicit diverse mathematical ideas among the students, it was not easy. In small group discussions, when a student was asked to validate an answer, he simply listed the mathematical properties instead of identifying the mathematical relationship behind the pattern. The students often said, “Ask the math teacher!” or “He is second to none in math” as a ground for their claim. This kind of justification was not enough to advance the students’ mathematical exploration. It is interesting to point out that justifications that relied on authority appeared only in the initial stage of inquiry when students hadn’t learned how to make argumentation with a valid warrant. When the teacher noticed that, she decided to play a discursive role proactively to facilitate the students to engage with mathematical inquiry more seriously.

Thus, the teacher held a whole class discussion and prompted the students to construct justification with mathematically meaningful warrant and encouraged their active argumentation. During class, we observed that, due to this expectation of the teacher, the students began to make mathematically meaningful justifications by seeking valid warrants for their claims, answering back with questions such as, “How did you get these triangular numbers?” or “Let’s explain why”, in their preparation for whole class presentation. They also began to develop discussions about a challenging problem in a substantial manner. The students checked each other’s answers and collected opinions regarding how to solve the problem. The intervention that the students should present their results from the small group discussion to the whole class gave students an opportunity to review their answers once again and strengthen the warrant, which, in turn, improved the level of students’ justification.

In the early stage of the instructional intervention, the students often constructed single argumentation structure. In the retrospective analysis, the teacher said that it might be because of tasks using concrete and tangible objects. In other words, when the students worked on the patterns among concrete and tangible objects, the students tended to rely on the visual representation of the task. Thus, they might not see the necessity for mathematical explanation about the pattern, since they considered that it was visually obvious. The students often used a formula that they knew by memorization and didn’t recognize the limitations of that formula in the whole class discussion. The teacher pointed out to the students that students’ display of knowledge simply by memorizing a formula is not good enough to justify their thinking. This reflection suggested that we needed to change the task that stimulated students’ justification processes.

### **Stage two: Multiple argumentation**

In stage two, there were also two sessions. Based on the reflection of Stage One, the teacher thought that she needed to present counter examples to the formula that the students used in Sessions 2 and 3. The teacher revised the tasks to help the students learn that it is important to understand the mathematical meaning of a formula in problem solving. So the final question presented in the Session 3 was; “How many cans are needed for a shop manager to make a shape which looks like camelback as shown in (Figure 4)?” It is not easy to directly apply the formula getting a triangular number to this question (Figure 4).





Figure 4: Task figure in session 3

The students found the answer of 111 in diverse ways using what they had learned earlier, and the whole class discussion proceeded briskly with the students' explanation about the method of their solutions. At the whole class discussion, teacher used questions such as "Have you found the answer?", "Have you found any other methods?", "Who is next?" to facilitate students' thinking. As a result, students presented six different warrants: counting them all one by one in pairs (W1), using the formula for the triangular numbers for the upper part of the figure and counting the rest one by one or counting half of them and then doubling (W2), dividing the figure into as many triangles as possible to use the formula for triangular numbers and counting the rest (W3), splitting the figure into two triangles and deducting the overlapping part by calculating it with the formula for triangular numbers (W4), just counting (W5) and making a triangular based on the bottom side and deducting the newly added two triangles using the formula for triangular numbers (W6). There were rebuttals (R) to two of the warrants (W2, W6) and one backing (B) to one of warrants (W6) (See Figure 5).

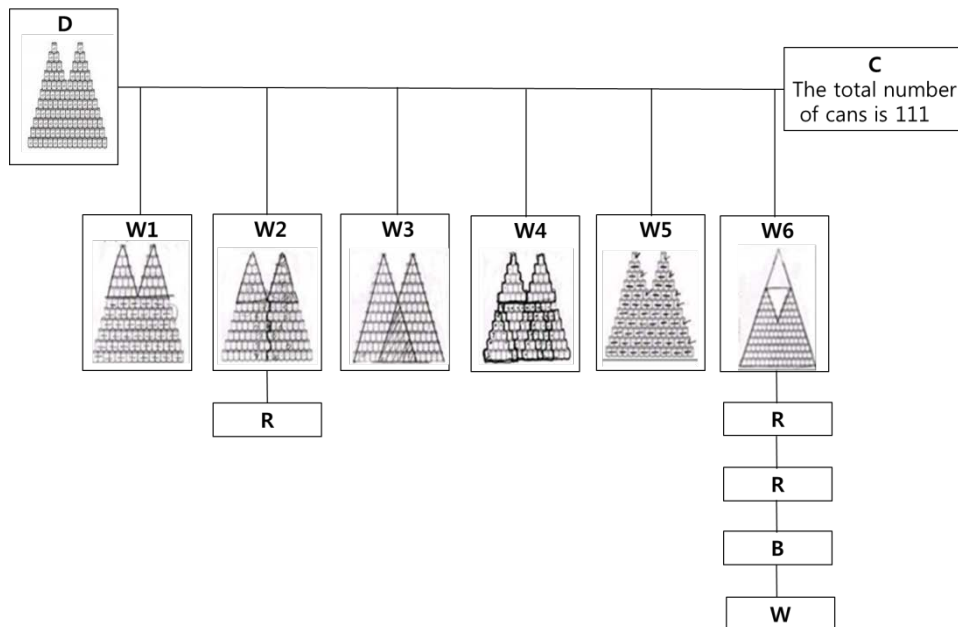


Figure 5: Argumentation in the whole class discussion (session 3)

This argumentation can be classified as multiple argumentation structure because it uses two or more inference rules to show the validity of the claim. This type of justification relies upon the knowledge validated on knowledge already possessed by the students.

Particularly because the problems in Session 3 were applications of what they had learned in Sessions 1 and 2, the students used what they learned in the earlier sessions for justifying their solutions.

For the task with various solutions, the teacher asked questions such as “Are there any other methods?”, “Who is next?”, and “It looks like a good way. Are there any other ways?” In this way, she helped students to acknowledge the value of the diversity in the practice of mathematics and encouraged them to bring up various justifications. In the whole class discussion, almost all the students tried to divide the figure into triangles, in order to use the formula for triangular numbers that they learned in Sessions 1 and 2. The students did so, however, without asking themselves why it should be divided into triangles. The teacher asked the students “Why did you divide it like that?” This question led the students to offer the warrant for their justification. The students were able to offer a warrant for the method they used.

Yet in Stage two students did not go beyond searching for patterns, and so the teacher decided to intervene more actively in the small group discussion to develop students’ deductive justification. In this stage, the task was focused on applicable objects from concrete and tangible object. In stage three, researchers judged that students would have difficulty in finding general relations in the patterns, so there were intensive discussions about how instructional scaffolding could help students accomplish this goal. Our research team decided tasks for generalization would help the students’ progressive mathematization in the following two sessions. The researchers were strongly convinced that the teacher’s active intervention by asking questions was essential in helping students engage in collaborative inquiry.

**Stage three: Compound argumentation**

In stage three, there were two sessions. In the beginning of the implementation, single argumentation structure was prevalent in the students’ argumentation and justification. Multiple argumentation structure evolved as the teacher intervened in the students’ practice of mathematics by modifying the level of the task complexity and classroom activity. The argumentation structure constructed by the students became gradually became more complicated. The students began to construct more sophisticated justifications for their mathematical claim in collaboration. The most salient property of Stage Three is that compound argumentation structure, the most complicated and sophisticated kind of argumentation, emerged.

The tasks in Session 4 asked students to find the patterns of ordinary materials such as a ping-pong game or a number strip. In dealing with the tasks, the students spontaneously produced both pre-formal justifications and formal justifications. Thus the teaching materials for the class were restructured to skip the tasks and shift to a learning stage in which a generalization formula is established directly. For instance, the first task in Session 5 was concerned with exploring V-pattern figures to find a pattern. It asked whether it is possible to make this V-pattern figure with 35, 778 dots (Figure 6).

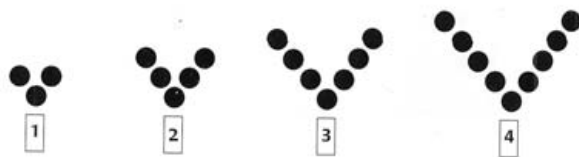


Figure 6: The diagram used in the first task in session 5

In small group discussion, the students had difficulties with the logical exploration of their claim. So the teacher intervened and asked questions to induce the students' justification. The students tried to explain them with their own expressions. For example, the teacher made comments like "You must be able to explain.", "How can you explain any other method?" and "First, write down everything you have in mind." to demand explanation for students' claim and the warrant that can back up their claim. Also, questions were raised when the students offered unclear warrants such as "It is impossible because it is an even number." or "They grow both sides from this point." Those kinds of questions facilitated the students to justify their warrant more carefully. The active intervention of the teacher by giving comments in the small group discussion helped the students produce multiple argumentation structures since the teachers' comments encouraged the students' warrant and backing.

The following is the second task presented in Session 5. It is to find a general formula for the number of the dots presented in W-pattern in each stage after learning how to get the number of V-pattern dots in the first task (Figure 7).

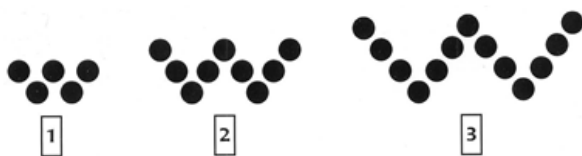


Figure 7: The diagram used in the second task in session 5

In the small group discussions, students sometimes used empirical justification by inductive thinking as their warrant. However, since the numbers of the patterns changed, the students became interested in the numbers changing in each stage and had discussion to make pre-formal justification and justification through a formal warrant. In this context, the teacher intervened in the students' discussion and requested a more detailed explanation why they thought that.

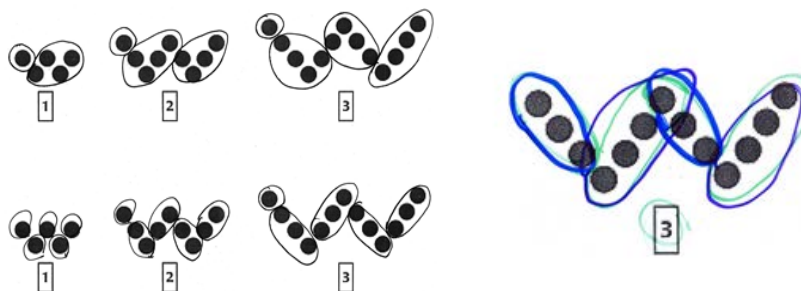


Figure 8: An example of students' warrants in the second task in session 5

The student bundled the dots as given in the left part of Figure 8, and made the formula of ' $4n+1$ '. Also, there was a student who created formal justification of ' $2n+2(n+1)-1=4n+1$ ' in small group discussion. As shown in the right part of Figure 8, it made two bundles with the pattern number of [3] and two other bundles by adding one to the pattern number and then deducted the one overlapping dot. Such variety of justifications corresponded to a warrant, and supported the argumentation and enriched the quality of the argumentation (Figure 9).

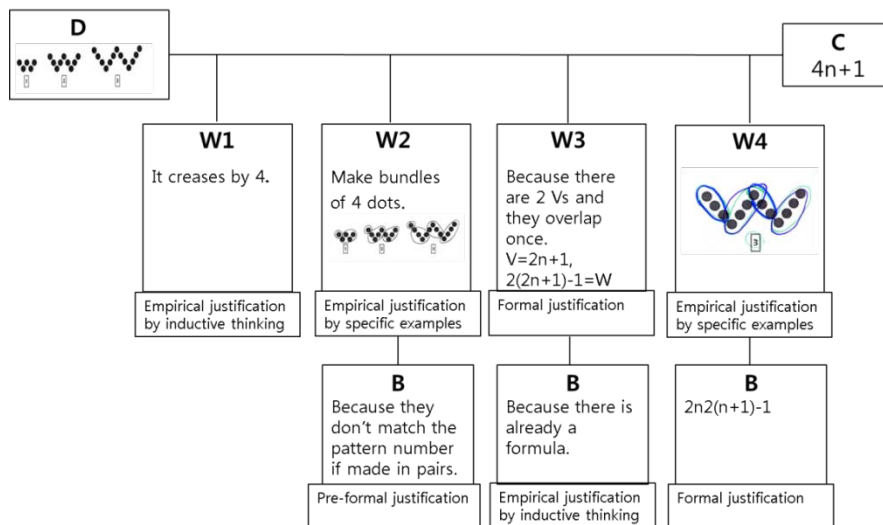


Figure 9: Argumentation in a small-group discussion for the second task in session 5

In whole class discussion, the students had active conversations about the conclusion of “ $4n+1$ ” from various viewpoints on the basis of the results from small group discussion. As a result, they obtained mathematical justification and enriched argumentation. Instead of easily accepting the conclusion of ‘ $4n+1$ ’, the students constructed refined argumentation about the different ways of making bundles with the dots. For instance, Student B made a rebuttal [R] to student A’s claim [W1,B], and student C applied Student B’s solution to patterns [1] and [2] saying that the pattern of numbers must match the number of dots in each bundle [W2,B2]. After argumentation, the students decided that the two methods are different claims. And other students presented warrants [W3, W3’] and backings [B3, B3’] for each claim. Finally, they agreed to the conclusion of Student C [C3] and the argumentation ended.

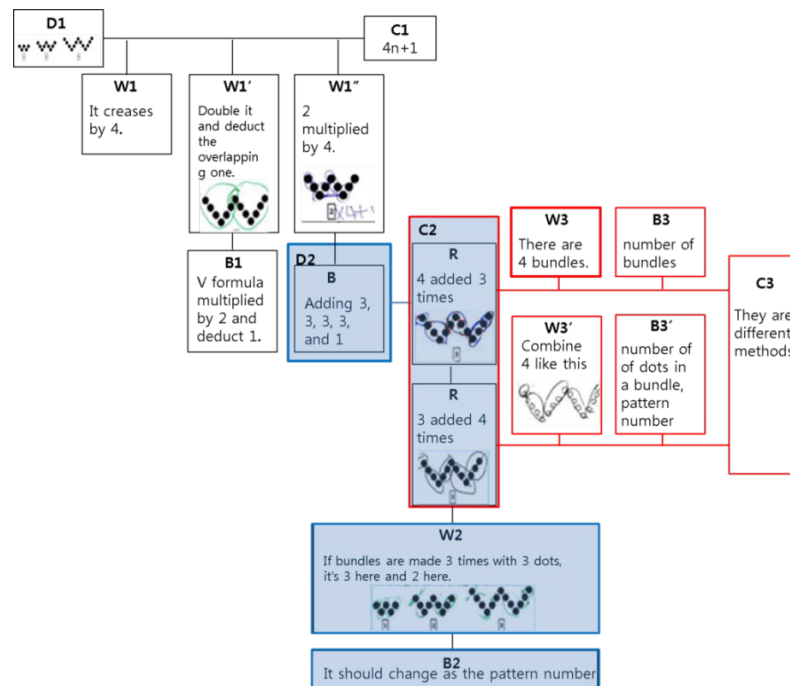


Figure 10: An example of compound argumentation in session 5

As described in the above case, the compound argumentation, which had not been observed in previous sessions, appeared in the whole class discussion in the latter part of Session 5. Figure 10 shows a synthesis of three multiple argumentations. In the shaded second argumentation, the backing in the first argumentation of '4 added 3 times.' was used as data but as a claim for a rebuttal of '3 added 4times.'(R). Again, a new claim which used the claim used in the first argumentation as a data for a rebuttal to this claim and the warrant (W) and backing (B) comments to this claim followed. The students engaged in the discussion and reached a conclusion that the two claims in the second argumentation - the two claims that used the conclusion as data - were different methods. The processes by which W and B in each data set are used to arrive at this conclusion can be regarded as the third argumentation, and is marked in thick lines.

We found three important issues from this study. First, EDR allowed us to document the learning trajectories of students' argumentation and justification. Thus, the strength of EDR lies in the fact that it explicitly makes visible how didactical mechanisms of the instructional design for students' mathematical empowerment functions and becomes refined over time. Second, the intervention developed throughout the process of the study through documenting and reflecting upon the teaching and learning practices in class. For instance, we found from the analysis that teachers' discursive repertoire had been extended to more sophisticated ones in support of students' deeper understanding. Such design studies not only provide methodological enhancement but also improvement in instructional competence of teachers. Lastly, the changes in the intervention and students' learning were interwoven with one another as shown in Figure 11. This suggests that EDR is a valid research methodology for developing a pedagogical approach, which is responsive to students' learning styles.

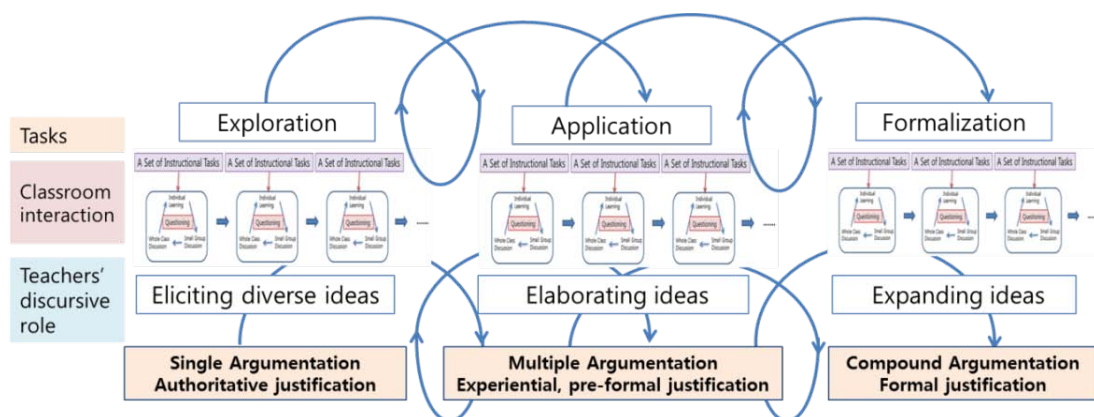


Figure 11: The development of students' argumentation and justification in relation to the intervention

## 5. Conclusion

In this chapter, we have described some of the central methodological and practical considerations of an effective instructional intervention for students' mathematical empowerment. Specifically, we focused on not only the emergent patterns of mathematical argumentation and justification but also the didactical mechanisms in the context of mathematical justification and argumentation. In revealing such emergent patterns and didactical mechanisms, EDR is an appropriate research approach.

The implications of our research are twofold. First, the methodological approach outlined in this chapter provides an example of how to design interventions (tasks, classroom interaction, and teachers' discursive role) unfold based on instructional design and conceptual framework, and also gives a big picture of how notions of argumentation and justification can be substantiated in a classroom setting through EDR process. Further, from the finding that mathematical justifications were the driving force of the qualitative development of the structure of students' argumentation (See Stages 1, 2, and 3), it offers insight into the quality of students' empowerment in which students are the active agents in the construction of understanding.

Second, documenting instructional strategies as a teacher can serve as a model for professional development, promoting the role of teachers as reflective practitioners in the context of educational innovations. For example, through the EDR process, the teacher in this study has developed her knowledge about her students' learning as well as a didactic discourse competence that helps facilitate her students' engagement and empowerment in mathematics. Such experiences can promote a more genuine understanding of teaching and learning that is context sensitive. The EDR process and context may provide an enriching framework to integrate teachers' practical knowledge with research-based practices and to generate innovative design ideas that will improve learning. We hope our research offers a viable new approach to professional development that has the potential to provide teachers with these important features for their teaching. Also our research can be useful as methodological tool in developing theory and refining interventions as suitable for a given context.

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## Design-based Research Strategies for Developing a Scientific Inquiry Curriculum in a Multi-User Virtual Environment

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# 11. Design-based research strategies for developing a scientific inquiry curriculum in a multi-user virtual environment<sup>1</sup>

Brian Nelson, Diane Jass Ketelhut, Jody Clarke, Cassie Bowman & Chris Dede

## Abstract

*This National Science Foundation funded project is studying graphical multi-user virtual environments (MUVEs) to investigate whether using this interactive medium in classroom settings can simulate real world experimentation and can provide students with engaging, meaningful learning experiences that enhance scientific literacy. In the project's River City<sup>th</sup> curriculum, teams of middle school students are asked to collaboratively solve a digital 19<sup>th</sup> century city's problems with illness, through interaction with digital artifacts, tacit clues, and computer-based 'agents' acting as mentors and colleagues in a virtual community of practice. This paper describes the design-based research strategy by which we are currently extending an educational MUVE environment and curriculum. Through several iterations of design-based research, we have refined our curriculum, the MUVE environment, and the theories underlying our design.*

## 1. Introduction

Scientific literacy -the capabilities (1) to understand the interrelationships among the natural world, technology, and science and (2) to apply scientific knowledge and skills to personal decision-making and the analysis of societal issues -is a major goal for education in the 21st century (AAAS, 1993; NRC, 1996). Research suggests that, if all students are to become scientifically literate citizens, science instruction must convey greater engagement and meaning to them. To achieve this, we believe that science instruction in secondary schools should provide students with opportunities to explore the world; to apply scientific principles; to sample and analyze data; and to make connections among these explorations, their personal lives, and their communities. However, given the constraints of classroom settings, real world data collection and laboratory experiments are often difficult to conduct. It is no surprise, therefore, that science experimental design, are among the most difficult challenges they face.

With NSF funding, we have created graphical multi-user virtual environments (MUVEs) to enhance middle school students' motivation and learning about science and society (<http://rivercity.activeworlds.com>). MUVEs are similar to some online multi-player games in that they enable multiple participants to access virtual worlds simultaneously and to interact with digital artifacts.

<sup>1</sup> This contribution is based on the following publication with permission of the editor: Credits Nelson, B., Ketelhut, D., Clarke, J., Bowman, C., & Dede, C. (2005). Design-Based Research Strategies for Developing a Scientific Inquiry Curriculum in a Multi-User Virtual Environment. *Educational Technology* 45, 1 (January-February), 21-28.

Participants negotiate the worlds through their computerized representations -avatars, interacting with other students and with computer-based agents to facilitate collaborative learning activities of various types. Unlike many online multi-player games, our “River City” MUVE is centered on skills of hypothesis formation and experimental design, as well as on content related to national standards and assessments in biology and ecology.

We are conducting a series of studies to determine if virtual environments can simulate real world experimentation and can provide students with engaging, meaningful learning experiences that enhance scientific literacy.

We are employing a design-based research (DBR) approach to the iterative, formative development of River City and to resolving the scalability issues involved in moving to large-scale implementations.

In this paper, we reflect on our design-based methodology and discuss what we have learned using DBR in several cycles of implementations. By offering a ‘glass-box’ view into our research strategy, we hope to provide a guide to others interested in design-based research.

Our goal for River City is to promote learning for all students, particularly those unengaged or low performing. Using an open-ended design, students learn to behave as scientists through they collaboratively identifying problems via observation and inference, forming and testing hypotheses, and deducing evidence based conclusions about underlying causes.

The River City virtual “world” consists of a city with a river running through it; different forms of terrain that influence water runoff; and various neighbourhoods and institutions, such as a hospital and a university. The learners themselves populate the city in teams of three, along with computer-based agents, digital objects that can include video clips, and the avatars of instructors (Figure 1). Content in the right-hand interface-window shifts based on what participants interact with in the virtual environment (Figure 2). Chat text and computer agent dialogs are shown in the text box below these two windows; members of each team can communicate regardless of distance, but intra-team chat is displayed only to members of that team.



Figure 1

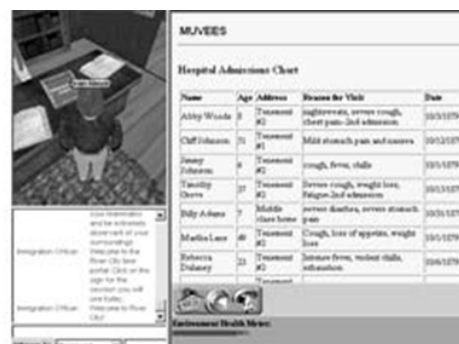


Figure 2

Students work in teams to develop hypotheses regarding one of three strands of illness in River City (water-borne, air-borne, and insect-borne). These three disease strands are integrated with historical, social and geographical content to allow students to experience the realities of disentangling multi-causal problems embedded within a complex environment. At the end of the project, students compare their research with other teams of students to discover the many potential hypotheses and avenues of investigation to explore.

## 2. Theories underlying the design

River City was originally designed as a guided social constructivist environment that allowed students to explore and focus on what intrigued them. The open-ended nature served as a members and the teacher. Observations of implementations provided evidence as to whether this was effective.

We were also interested in designing a curriculum that would appeal to both boys and girls. Research suggests that middle school is the developmental level where girls tend to lose interest in science (AAUW, 1999; Butler, 2000).

Therefore, in our design of River City, we intentionally created a lead female role model for girls. This model, Ellen Swallow Richards, was the first woman to earn a chemistry degree at MIT; she potentially combats stereotypes internalized by young woman. Further, research on gender and technology suggests that girls prefer environments that are collaborative in nature (Clark, 1999). This was an additional support to our decision to design the curriculum around teams such that students work collaboratively to solve the health problems in River City.

## 3. Cycles of implementations, findings and implications

### First cycle

#### *Implementation*

In our pilot implementations of River City, using two public school classrooms in urban Massachusetts, we examined usability, student motivation, student learning, and classroom implementation issues (Dede & Ketelhut, 2003).

One sixth- and one seventh-grade classroom in different schools with high percentages of ESL students implemented the MUVE-based River City curriculum; two matching control classrooms used a curriculum similar in content and pedagogy, but delivered via paper-based materials.

Using design-based research methods, we collected both qualitative and quantitative data from students and teachers over a three-week implementation period. Both the Patterns for and post-intervention. In addition, demographic data and teachers' expectations of students' success were collected. All teachers responded to a pre- and post-questionnaire regarding their methods and comfort with technology. The experimental intervention classroom teachers also wrote a narrative at the end of the project about their perceptions of the MUVE. We used this data, plus our own observations, to analyze the learning outcomes for students and to inform our understanding of how the MUVE worked, in order to refine the design of our next iteration and to reflect on the theoretical foundations underlying our design.

#### *Findings*

Results indicated that the MUVE was motivating for all students, including students who had been characterized as "low ability", based on grades. For example, six out of seven experimental students who scored in the bottom-third on the content pre-test improved to average or above; however, only two out of five control students who scored in the bottom-third on the pre-test moved out of this category. We also found that the ability to engage in inquiry in an authentic setting was powerful for students. They discovered multiple intriguing health problems in the MUVE to investigate. In the seventh grade classroom, five different hypotheses about the health problems emerged, with posited causes ranging from population density to immigration to water pollution. The MUVE seemed to have the most positive effects for students with high perceptions of their own thoughtfulness of inquiry (Dede & Ketelhut, 2003). In our analysis, we found that gender was consistently not a significant predictor of success in

the River City MUVE. However, we did find that on our pretest, six out of our eleven lowest performing students were female. Focused analysis on these 6 students led to an interesting discovery of the effect of the MUVE. The science self-efficacy of these females, the Similarly but with a smaller effect, their motivation also increased.

### ***Implications***

Overall, these findings encouraged further refinement and experimentation with curricular MUVES to help teachers reach students struggling with motivation and lack of content knowledge. By examining recorded and observed student interactions with the pilot curriculum, we saw ways to strengthen our content and pedagogy. Although students found the MUVE readily usable and the learning experiences motivating, we found weaknesses in this design, both from a graphical and curricular perspective.

Based on our analysis of the first River City pilot study, we refined the MUVE environment.

In the initial environment, computer-based River City 'citizens' recited lines of text repeatedly as students approached. However, students could not interact with the citizens in any way. Based on student feedback, this was changed so that students could ask basic questions such as "What's new?" to the citizens to gather clues about events in the city. Students also gained the ability to teleport (move instantly) to different locations within the virtual city. The virtual area of River City is quite large, and students expressed the wish to be able to cover more area quickly. Finally, students were given the ability to choose their avatar, to enable more self-expression in the world.

From a theoretical perspective, all these were ways of increasing students' psychological immersion in the MUVE, through adding new types of actions, social situations, and participation in the learning environment.

## **Second cycle**

### ***Implementation***

Our first implementation of the revised MUVE curriculum was held in a small focus group in December, 2003; we concentrated our evaluation on the student responses to the new changes: interactive residents, teleporting map, and ability to choose and change their avatar. We observed student interactions and conducted exit interviews with them; we also actively solicited focus group suggestions of changes students would like to see.

### ***Findings***

From our observation of focus group participants, we noticed that our three changes seemed to elicit 'ah-ha' moments for students. From observations and these interviews, we further learned:

- Students needed time to experience the world before beginning the formal curriculum. This experience helps them to become immersed in the context.
- Students were confused by the connection and relevance of the digitized Smithsonian artifacts in the world.
- Some students became easily lost in the world.
- Students sought to access the books in the virtual library of River City when they were confused.
- Students wondered why their avatars were not also getting sick.



### ***Implication***

Based on this implementation, we concluded that our changes had been positive and should be kept, but additional modifications were needed:

- A reorganization of our lab book to allow students time to learn how to maneuver, and to explore the world.
- A new section to our lab book that guides students in understanding the digital images and artifacts embedded in the world.
- A permanent link on the interface to the interactive map.
- A health meter that would rise and fall as students wandered close to polluted waters or stepped on manure.

Theoretically, many of these changes increase the guidance provided to students as they experience social constructivist learning.

### **Third cycle**

#### ***Implementation***

We made these design changes and then conducted two full-scale pilot studies in January and February 2004. These implementations included similar pre and post assessments to those used in the first cycle of implementations.

The January implementation was conducted in an informal after-school program, and the February implementation was conducted in a west coast university laboratory school. Both of these represented different populations to our public school populations used in the previous cycle, so we focused our attention to see if our changes worked even as our participants changed.

#### ***Findings***

As we implemented this new version, we determined that our alterations made significant improvements to the curriculum, resulting in improvements in student engagement and learning outcomes:

- We found that providing time for initial exploration of the environment resulted in students being immediately engaged. They used this time both to become comfortable with the MUVE interface and to start understanding what problems existed in River City. When we handed out the lab book on the second day, the students used this to guide their investigation more readily than they had previously.
- Prior to creating the new lab book section on artifacts, we found that students were likely to primarily rely on computer-based agents to understand the problems in River City. Since much of the curriculum is attached to embedded artifacts, students were limiting their understanding. After creating this section, students increased their interactions with the digital pictures, thus increasing their involvement with the curriculum.
- Students found that the teleporting map facilitated finding where they were or where they wanted to go; this increased their mobility and allowed students to access more of the curriculum than previously. However, students still complained that it was difficult to locate themselves on the map.
- Once the students discovered that they could “find answers” in the library using the new dictionary, encyclopedia, primers on microbes and scientific method and algebraic concepts (which to many middle-school students was another ah-ha moment!), it became a popular place to get more information.
- Students used the health meter as an additional source for data in their experimentation.

As they walked through the world, the movement of the meter intrigued students enough that they explored ways to make it change. As a result, students realized where the pollution and contamination in River City was at an earlier stage.

- Teachers commented that it would be great if students could actually conduct experiments in the world.

### ***Implications***

Actual experimentation in the world had previously been technologically impossible. Improvements to the technology now made that a possibility. Given our emphasis on authentic learning, this modification was made in the next cycle of implementations. In our initial implementations, we constantly evaluated the appropriateness of our underlying pedagogical theory of constructivism. As our design became stronger, we turned our attention to evaluating our pedagogy. In River City, students are immersed in conducting an authentic task, similar to 'learning on the job.' This seemed more similar to situated learning than constructivism. Situated learning requires real-world contexts, activities, and assessments coupled with guidance based on expert modeling, situated mentoring, and gradually increasing participation. MUVEs are a promising medium for creating and studying situated learning because they can support immersive experiences (incorporating modeling and mentoring) about problems and contexts similar to the real world, situated learning pedagogy to one based on guided social constructivism. Both in and out of MUVEs, insights obtained by this comparison may enhance educators' and researchers' understanding and application of learning theories and may increase students' abilities to transfer knowledge from academic to real world settings. A major benefit of a DBR approach is that it promotes evaluation and redesign of the underlying theory.

### **Fourth cycle**

#### ***Implementation***

Based upon what we learned from the first pilot study, we developed two variations of the River City curriculum. Variant GSC centers on the original guided social constructivist (GSC) model of learning, in which guided inquiry experiences in the MUVE alternate with in-class interpretive sessions. Variant EMC shifts the learning model to center on expert modeling and coaching (EMC), with expert agents embedded in the MUVE and experts collaborating with teachers in facilitating the in-class interpretive sessions. Our third "control" condition utilizes a curriculum in which the same content and skills are taught in equivalent time to comparable students in a paper-based format without technology, using a guided social constructivist-based pedagogy. Where possible, teachers offer both the experimental and the control curricula.

To control for threats to validity, both variants were randomly assigned to students within a single classroom, with teachers instructed to minimize cross-contamination of treatments. We also created approximately eight hours of professional development for teachers, focused on content review, alternative pedagogical strategies based on different theories of learning, facilitation strategies while students are using the MUVE, and interpretive strategies for leading implementations.

As a result of the previous pilot studies and attendant refinements, we scaled up our implementation of the River City curriculum in spring 2004 with eleven teachers and more than 1000 students spread over two states and three school districts.

#### ***Findings***

We are now in the midst of analyzing data from this implementation and early results are promising. Preliminary findings show that both students and teachers were highly engaged. All of the teachers who responded to the post-implementation survey said they would like to use the River City curriculum again. In interviews and focus groups, students said they 'felt like a scientist for the first time' and asked when River City would be available for purchase. In some of the urban classrooms in the Midwest where low attendance and disruptive behavior are daily struggles for teachers, we found that student attendance improved and disruptive behavior dropped during the three-week implementation.

Interesting patterns are emerging about which students did best under our various pedagogical conditions. More specifically, of the nearly 300 students who have been analyzed to date, students in the two experimental treatments improved their biological knowledge by 32% for GSC and 35% for EMC. Control students also improved, but by only 17%. Improvements were also seen across the board for knowledge and application of scientific processes. In this case, the control students improved slightly more than the other two groups: 20% for the control, 18% for the GSC group and 16% for the EMC group.

Given the complexity of the MUVE environment, we are looking at multiple measurements of student learning. For example, after conducting their experiment, students are Preliminary analysis of students' written letters to the mayor of River City suggest that students demonstrate an understanding of the process of the scientific method that was not well captured in the science inquiry post-test measures. For example, students who scored low on the science inquiry post-test wrote letters that were of similar quality to those written by students who scored higher on the post-test. Interestingly, more of the lower-performing test students met the criteria of providing suggested interventions or further research than students who scored higher on the inquiry test questions. This suggests that the complexity of the MUVE treatment creates intricate patterns of learning more appropriately measured with an authentic activity, such as writing an experimental report.

To assess the success of our changes to the environment, we asked students about the tools and avatar choices. Students were overwhelmingly positive about both, listing their favourites amongst the choices of avatars. However, uninitiated, they again mentioned the desire to see themselves on the map of River City.

### ***Implications***

Based on our interesting findings comparing GSC and EMC, we will be adding a new theoretical treatment in our next implementation. Variant LPP shifts the learning model to focus on legitimate peripheral participation, in which the entire community of practice in the MUVE works on problem-solving, and students learn more from observation of somewhat more advanced participants (avatars, computer-based agents) than via direct guidance by experts.

For this fourth cycle, we expanded the capabilities of our water sampling station to allow students to take random water samples. Students are now able to click on any of fourteen water stations and bring up an image similar to what they might see in a modern day microscope (see Figure 3).

They can now take multiple samples and test for bacteria in the water as a scientist would in the real world.

Given the success of this tool on students' engagement, we are currently developing three other tools that help students conduct tests related to the other diseases: a mosquito catcher, blood tests, and throat swabs.

We plan to explore the affect of tool use and ability to conduct tests on students learning and feeling like a scientist in future implementations.

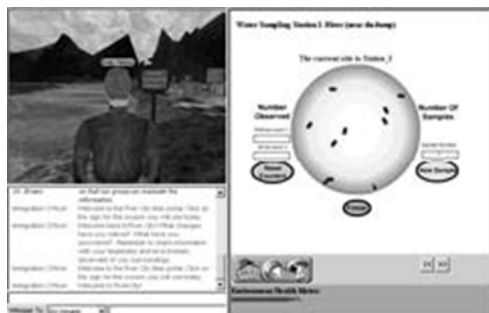


Figure 3: Taking a water sample

Based on student feedback and improvements in the technology, the map will now track individual student movement in the world. This will allow students to 'see' themselves and researchers to track student exploration. This information will help us gain a better understanding of how students' interactions in the world affect their learning.

Assessment of learning continues to be problematic for us. Given our differential pattern of results from qualitative and quantitative sources, we are continuing to look into better ways at the end of our unit to measure all the various types student learning we see in classroom observations.

As a result of teacher request, and because scientific inquiry is difficult to enact in a classroom, we created an extensive online professional development for teachers. However, we found that very few teachers interacted with the online materials. We are redesigning our professional development integrating face-to-face meetings with online resources and follow-up sessions. We are also including a more extensive section on the teacher's role in River City and how to facilitate whole class discussions that wrap around the activities.

#### **4. Implications for practice, policy, design, and theory**

An important emphasis in our research is to increase student motivation, self-efficacy, and scientific literacy. In particular, educators need help in engaging and teaching approaches, and pupils with learning styles more visual and kinesthetic than symbolic and auditory. In a typical middle-school classroom faced with a diverse set of learning styles, the teacher must alternate pedagogical strategies to aid each of these. Even under the best of circumstances, at any single moment some students' learning preferences block them from understanding the lesson. In a MUVE, students can individualize their learning based on their own styles. Our environment/curriculum is targeted specifically to narrowing the gaps among students by helping all learners reach their full potential, especially students who are currently underperforming because of how they are taught in conventional classroom settings. DBR methodologies are providing a way of identifying which elements of our curriculum and MUVE environment are best suited to this goal.

By engaging in DBR-inspired cycles of design, implementation, analysis, and redesign, we have been able to refine both our curriculum and the MUVE environment prior to conducting formal randomized experimental trials. In each implementation cycle, quantitative data are revealing findings about the relative effectiveness of learning theories as instantiated in our environment/curriculum. Qualitative data are providing insights about the reasons underlying those comparative differences. In addition, our quantitative studies, including the use of a control curriculum, are helping us determine whether the leverage for learning and engagement provided by our work are substantial enough to merit moving beyond DBR to large-scale experimental research on implementation.

Dede (2004) states that an important challenge in design-based research is determining what constitute reasonable criteria for “success” in declaring a design finished. After several study iterations, substantial parts of the design have remained relatively unchanged from the objectives. Other parts of the design have changed based on feedback from the initial studies. For example, identity plays an important role in learning (Lave and Wenger, 1991) and research on identity in virtual environments suggests that females like to play with their identity (Turkle, 1997). While we improved our design to allow students to select different types of avatars, some students from our February implementation wanted to be able to design their own avatar, rather than choose a pre-designed one. While we do not expect boys and girls to have the same experience in River City, we would like them to have equally satisfying experiences. Our findings consistently show this to be true. Therefore, in our case, the ability to create one’s avatar does not appear to be a condition for success. Thus, we have determined that aspect of our design is finished.

## 5. Conclusion

We believe that this type of controlled evolution of DBR is important to its acceptance as a legitimate methodology by the conservative end of the scholarly community in education. We hope to contribute to the field and legitimacy of DBR by sharing our development strategy in the context of our MUVE science curriculum.

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## Developing an Intervention to Increase Engaged Reading Among Adolescents

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# 12. Developing an intervention to increase engaged reading among adolescents

Gay Ivey

## Abstract

*Although engaged reading is associated with increased reading achievement, it is on the decline among adolescents. Using design research, an intervention to increase engaged reading was developed for all 8<sup>th</sup> grade English classrooms in one United States school. The initial instructional model centered on self-selected, self-regulated reading in high interest young adult literature. Modifications resulted in an instructional framework that included increased attention and access to diverse books, proactive teacher one-to-one instruction with inexperienced readers, and time set aside for peer talk. In addition to the outcome of increased engagement, unanticipated outcomes included student perceptions of change in how they thought about their lives and their wellbeing connected to the types of texts they read and parent involvement in engaged reading activities.*

## 1. Introduction

Student engagement is associated not only with academic achievement (Fredricks, Blumenfeld, & Paris, 2004), but with a host of other benefits, including school attendance, graduation, and academic resilience (Connell, Spencer, & Aber, 1994; Finn & Rock, 1997; Skinner, Zimmer-Gembeck & Connell, 1998), as well as social regulation (Perry, Phillips, & Dowler, 2004) and social competence (Catalano, Berglund, Ryan, Lonczak, & Hawkins, 2001). Thus, the decline in student engagement in United States schools across the school years (Dotterer, McHale, & Crouter, 2009) is a substantial problem. Engagement with reading, in particular, is on the decline (Rampey, Dion, & Donahue, 2009). Creating and implementing a curriculum that is rich and meaningful and that also engages students representing a range of cultural and academic experiences may be perceived as a lofty and perhaps inaccessible goal (Eccles & Roesser, 2011). The possibilities for catalyzing reading engagement, though, are promising (Wigfield et al., 2008).

The purpose of this study was to take up the challenge of increasing reading engagement in all eighth grade English classrooms in one school. Design research is a logical match for developing an intervention to increase engagement in secondary English classrooms, which have been resistant to change for decades (Sewell, 2008; Yagleski, 2005). However, interventions aimed at expanding engaged reading have been successful in other contexts, particularly in the earlier grades. Guthrie and his colleagues (e.g., Guthrie, Van Meter, McCann, & Wigfield, 1996; Guthrie, Wigfield, Barbosa, Perencevich, Taboada, & Davis, 2004) have for several decades reported studies of increasing reading engagement in elementary school classrooms, and more recently, in seventh grade English language arts classrooms, but with a focus on science reading (Guthrie, Klauda, & Ho, 2013). Taboada and Buehl (2012) described an intervention to increase engaged reading in science within linguistically diverse fourth grade classrooms. Still, with the exception of the Guthrie Klauda and Ho study focusing on science reading within a unit of study (2013), and a formative experiment by Ivey and Broaddus (2007) designed to increase reading engagement among seventh- and eighth-grade Latino students

just beginning to read, write, and speak English, interventions in middle and secondary classrooms are difficult to find. The present study focused on building an intervention in eighth grade English language arts classrooms that included students representing a range of academic achievement and cultural and linguistic differences. Furthermore, the focus of reading was not limited to certain types of texts or concerning a particular dimension of the curriculum (e.g. science concepts or historical information). The goal of the intervention was to help students development engagement in reading, unconstrained by a specific content focus.

The overriding question posed in this study was “What are the instructional characteristics and processes necessary to increase reading engagement among students in 8<sup>th</sup> grade English classrooms?” In planning, implementing, and interpreting this study, I adopted the framework for conducting design experiments suggested by Reinking and Bradley (2008):

- Identify a pedagogical goal that has theoretical value and an empirical base suggesting the potential for achieving that goal.
- Design a theoretically promising intervention aimed at achieving the goal.
- Determine the factors inhibiting or enhancing the effectiveness of the intervention.
- Modify the intervention to achieve the pedagogical goal in ways that are appealing to a range of stakeholders.
- Identify positive or negative unanticipated outcomes of the intervention.
- Recognize changes in the instructional environment due to the intervention.

In this chapter, first I provide the conceptual framework that more fully elaborates the value of the pedagogical goal of increasing engagement and provides the theoretically underpinnings of the classroom intervention. Second, I describe the research design, in particular, the five phases that constituted the experiment. Third, I briefly summarize the intervention in its modified form with guiding principles for future implementation. Fourth, I offer reflections on the study and subsequent and current work that was catalyzed by the engineering and results of the intervention.

## **2. Engaged reading as a promising pedagogical goal**

Reading engagement has the potential to contribute powerfully to literate development (Guthrie & Wigfield, 2000) and literate achievement (OECD, 2010), but little research has focused on classroom settings arranged to increase literacy engagement in middle and secondary school classrooms. In fact, existing research has circled the issue without explicitly taking it up. Studies on attitudes toward reading have helped identify the problem, which appears to have changed little over time. Studies from nearly two decades ago (Ley, Scher, & Dismukes, 1994; McKenna, Kear, & Ellsworth, 1995) provide evidence for a decline in feelings about reading throughout the middle grades, and a more recent study by McKenna, Conradi, Lawrence, Jang and Meyer (2012) indicate that not much has changed, even as newer kinds of texts are considered. They identified a decline in attitudes toward recreational print reading, recreational digital reading, and academic digital reading from grades six through eight, and a consistently negative attitude toward academic print reading in those grade levels.

However, attitudes toward reading may be associated with school purposes for reading versus students' own reasons, since motivation to read is not a fixed construct (Baker & Wigfield, 1999). Perceived relevance and a sense of autonomy, in particular, are foundational to intrinsic motivation, particularly for adolescent readers (Guthrie, Wigfield, & Klauda, 2012). In this section, I address these two constructs in relation to adolescents' reading motivation and engagement.

### **Perceived relevance and reading materials**

Middle school students report that they would be motivated to read given significant time to read in school, books they prefer, and teachers who read aloud to them (Ivey & Broaddus, 2001), but they also indicated that the texts they would like to read are not available in school (Ivey & Broaddus, 2001; Worthy, Moorman, & Turner, 1999). Related, over the past few decades, a host of researchers have examined adolescents' out-of-school literacies and the divide between school activities and nontraditional literate activities students engage in away from school, including for instance, tagging and graffiti related to gang membership (Moje, 2000), negotiating video games (Leander & Lovvorn, 2006), and socializing with peers (Finders, 1997). Moje and her colleagues (Moje, Overby, Tysvaer, & Morris, 2008) investigated the out-of-school literacy practices of youth within a predominantly Latino community. These students reported reading websites most frequently, followed by letters and notes, music lyrics, email, and magazines.

The absence of novels and other kinds of print reading as key factors to students' engagement in inquiries of students' preferred texts and practices is a phenomenon that merits more attention. A simple interpretation is that these materials are not valued by students and cannot compete with the experiences offered by modern and changing technologies. A different perspective is that when adolescents have knowledge of and access to the high-quality young adult literature that fuels their interests and helps them to realize new conceptual goals, their tendencies to read these texts increase radically. But these texts are simply not used in secondary English classrooms. A relevant finding from Moje and colleagues (2008) replicates Ivey's and Broaddus's (2001) findings on middle school students' motivation to read. In both studies, when students were asked to write about a favorite book, they did name young adult novels, but the titles they reported were conventional and dated works of fiction (e.g., *The Outsiders*, Hinton, 1967) typically purchased by schools as whole-class sets and assigned as required reading. Given that particular novels were named so frequently in both studies, one might infer not that these were students' favorite books, but instead the only titles they knew. Studies of reading preferences simply do not support the notion that students like these classic and conventional young adult books over other kinds of more contemporary, edgy fiction (Ivey & Broaddus, 2001; Worthy, Moorman, & Turner, 1999). Instead, adolescents are drawn to books they find relevant to their own lives and that mirror the complexities of their own social worlds (Moje et al., 2008). Many students depend on schools for access to and knowledge about reading materials, and since mainly teacher-preferred texts are available and used in classrooms (Worthy, Moorman, & Turner, 1999), it is unlikely they would find them on their own. The majority of the sample of adolescents in the Moje et al., (2008) study were economically disadvantaged and even had difficulty accessing the technology they said they preferred. In sum, although we know quite a bit about the texts that motivate adolescents to read, we know far less about the settings designed to increase their access to these texts and the resulting influence on their engagement.

### **Perceived autonomy and engagement**

Three types of engagement are described in the research literature (Fredricks, Blumenfeld, & Paris, 2004). Behavioral engagement refers to the act of participating in classroom activity as opposed to abstaining, acting out, or disrupting others. Emotional engagement (Csikszentmihalyi, 1990) is characterized by absorption in the task to the degree that one loses track of time and space. Cognitive engagement indicates self-regulated, strategic, and persistent action even when faced with challenge or task difficulty. These three types of engagement - behavioral, emotional, and cognitive - are likely interrelated and form a multidimensional construct (Guthrie & Wigfield, 2000) that is useful to the present study.

Key to engagement is the perception of having choice, and in particular, choices that are appealing (Flowerday, Schraw, & Stevens, 2004; Reeve, Nix, & Hamm, 2003). Having many options can be exasperating (Iyengar & Lepper, 2000) but good choices allow students to make connections to their personal goals. If engagement is a goal, then, teachers might consider deliberately understanding students' interests and designing instructional options to stimulate those interests (Katz & Assor, 2007). Related, students must experience feelings of autonomy, that is, that their efforts stem from their own purposes (Deci & Ryan, 1985). In contrast, frequent monitoring and external intrusions undermine autonomy (Assor, Kaplan, & Roth, 2002) and actually lessen engagement (Deci & Ryan, 1985). On the other hand social activities that are meaningful and that fuel feelings of relatedness and feelings of acceptance regarding personal interests and choices support engagement (Reis, Sheldon, Gable, Roscoe, & Ryan, 2000).

What we know about middle and high school English classrooms hints at the possibility that they operate in ways that obstruct engagement rather than facilitate it. Although teachers believe that choice improves motivation and learning, school structures and resources limit access to options that are personally interesting and relevant (Assor, Kaplan, & Roth, 2002). Secondary English classrooms in particular have not evolved much in the past 50 years. Students are provided little or no choice. Instead, they are assigned selections from the literary canon, and contemporary multicultural, multi-genre texts that students prefer are not prominent in the curriculum (Applebee, 1993; Sewell, 2008; Yagleski, 2005). Social events such as peer led discussions are rarely observed (Nystrand, 1997). In particular, general and special education populations are nearly always relegated to reading to a narrow collection of dated anthologies accompanied by textbook questions (Scherff & Piazza, 2008). The present study is an attempt to reverse the trend of disengagement with reading by disrupting these common practices with an intervention that specifically and deliberately aims for engagement. Guided by research on engagement, and in particular, engaged reading, the most promising intervention would fundamentally prioritize student autonomy (choice, limited teacher intrusion) and student relevance (high-interest texts).

### **3. Research design**

Design research is an appropriate methodological approach for determining the processes necessary for students to reach a particular pedagogical goal. In the case of reading engagement for adolescents, we have a sense of what motivates students and the reasons for disengagement. However, the question of how to initiate and sustain engagement across a large number of students given the day-to-day functioning and dynamics of classrooms is unanswerable by both conventional descriptive research and studies designed to measure "what works." There are good reasons to believe specific instructional changes would be necessary, and a design experiment provides data-driven opportunities to fine-tune an initial plan for engagement.

In this section I first describe the setting and participants, and the theoretically promising intervention that provided the foundation for the process. Second, I detail the nature of the design by describing five phases of activity leading to an evidence-based effective intervention.

#### **Participants and setting**

The setting for this study includes all eighth grade English classrooms in a public middle school (grades 6-8) serving a mid-Atlantic U.S. town with a population of approximately 22,000. Recent U.S. Census Bureau data indicate the median household income in this community is \$41,000, with 13% of persons living below the poverty line.

The school population is approximately 670 students across the following ethnic identities: 72% Caucasian; 16% African-American; 11% Hispanic; less than 1% American Indian/Alaskan; and less than 1% Asian/Pacific Islander. Forty-seven percent of students are eligible for free or reduced-priced school lunch.

Each of the four English teachers instructs three ninety-minute classes of students each day with 17-20 students per class. Two of the twelve classes are designated as honors classes, and two classes are designated as inclusive classrooms. During the year of the experiment, a total of 105 eighth grade students presented parental consent to participate in the study.

### **Initial intervention**

At the heart of the initial intervention for increasing engagement were three straightforward shifts in instruction based on the theoretical understanding that when students can read interesting texts that extend their own purposes rather than that of the teacher or the curriculum, they would be more inclined to read voluntarily. First, given the importance of personally compelling reading materials (Ivey & Broaddus, 2001; Worthy, Moorman, & Turner, 1999), teachers provided a range of multicultural, multi-genre young adult literature in lieu of a limited predetermined set of whole-class novels. Second, efforts were made to increase students' sense of autonomy, competence, and relatedness (Deci & Ryan, 1985) in reading. For autonomy support, individual students selected their own texts, reading at their own paces with the option of abandoning books that were not appealing. To support a sense of competence, texts representing a range of difficulty levels were provided as choices. To support a sense of relatedness, social interaction during and after reading was encouraged in the classrooms. Third, students made decisions on how to respond (or not to respond) to books they read. In other words, the reading of texts was not tied to projects (e.g., book reports) or other methods of external accountability; rather, the teachers adopted a no-strings-attached policy. Equally important to shifts in instruction was commitment to time for student reading in class. Because students insist they would read more if given adequate time in school (Ivey & Broaddus, 2001), teachers dedicated thirty minutes of each day's ninety-minute English block to uninterrupted silent reading. These priorities - access to high interest materials, student self-selection and self-pacing, and time - were established with the intention of providing students with as much control over the process as possible at first, leaving room for adjustments that might include more teacher involvement or narrower parameters if subsequent data collection and ongoing analysis indicated the need.

Teachers launched the intervention by setting aside two consecutive class periods to conduct a series of booktalks on texts from their classroom libraries, books that would be available for students to read voluntarily. These booktalks served as previews; teachers read aloud predetermined sections that exemplified the characters, problem(s), and tone of each story. Students were asked simply to listen, and teachers nudged them to write the titles of books they hoped to read across the year. Students were immediately allowed to peruse books and to begin reading. Thereafter, teachers provided an additional four to five booktalks each week before the designated reading time.

### **Phase I: What are students experiences with engaged reading prior to 8<sup>th</sup> grade?**

The purpose of Phase I was to establish a baseline for students' engagement with reading prior to the intervention. This was accomplished through a written questionnaire in which students were asked to describe past engaging experiences, identify specific titles of texts they found engaging, detail how teachers in past school years have helped increase their motivation to

read, and suggest what a person not motivated to read might do to become engaged. Results of the simple survey analysis indicated low reading engagement, for instance, only twenty percent of students could name a books they had found engaging, and only nineteen percent of students reported reading voluntarily outside of school.

**Phase II: How effective is an intervention centered on student autonomy and relevance on increasing students' reading engagement?**

I began student observations two weeks into the intervention, once teachers had introduced books and routines, and after students had some opportunities to choose texts and to read. Over a consecutive three week period, I (with the assistance of two graduate students) observed silent reading time in each of the twelve classes three times each week and conducted once-weekly observations of the full ninety-minute class period in three of the classes. During silent reading time observations, I completed a simple checklist of individual students' behavioral engagement (visibly engaged/not engaged), and I collected a qualitative accounting of related behaviors signaling the absence or presence of engagement (e.g., switching books three times during a thirty minute period; student initiating conversation about a book with a teacher or peer). During whole class period observations, I looked for signs of continued engagement with texts beyond the sanctioned silent reading time (e.g., students continue to read as the teacher moves on to other dimensions of instruction; students mention books they are reading during other activities, such as writing). The purpose of these observations was to determine the effectiveness of the intervention at increasing engagement, albeit from a behavioral perspective.

As an additional source of data, and one way to examine the extent of emotional engagement (and later the influence of relevance via reading materials), teachers constructed community book logs for each classroom. These notebooks included a separate page for each book available, and students recorded whether they had finished or abandoned the book, and they provided an overall rating (1-10), and brief qualitative evaluation and/or recommendation. For instance, students entered comments such as "This book made me cry so hard." During each week of this phase, I calculated the frequency of finishing books versus abandoning books.

During the third week of Phase II, I conducted twenty-four interviews with students identified by the teachers as key informants, both for triangulation and to get a sense of students' experiences not afforded by observation - emotional and cognitive engagement. The criteria for selecting students were a) they appeared either highly engaged or highly disengaged; and b) they were willing and able to provide rich information about their experiences. These interviews were semi-structured, but were designed to induce students to reflect broadly (e.g., "Tell me what has changed for you as a reader so far this year?") and specifically (e.g., "Have you read something recently so memorable you keep thinking about it or told someone else about it?" and "Have you abandoned a book? Tell me about that."). Students reported their awareness of reading willingly and enthusiastically in this setting versus experiences in prior school years, as one student put it, "I haven't read a single book since second grade, and this year so far, I've already read four books." Cognitive engagement was expressed widely in the context of what they did when reading became difficult, with many students reporting strategic activity and perseverance. For instance, one student reported, "I had read about fifteen pages, and I realized I didn't know what was going on, so I went back and read it again, and then it all made sense." Emotional engagement was apparent in students' comments about their emotions within particular books, for instance, "I got so mad at [the character] that I threw the book and my mom asked me what was wrong with me."



### **Phase III: What are the key factors of the intervention that are enhancing or inhibiting engaged reading?**

Phase I indicated that engaged reading was occurring for a substantial number of students, but that some students still struggled. Phase II focused on pinpointing the elements of the intervention that were helping to perpetuate engagement as well as the barriers to engaged reading. Student interviews were the most direct and useful strategy for identifying these factors. I began this process by re-analyzing the key informant interviews from Phase II, this time coding for student perspectives on the dimensions of the intervention that either helped to increase or hinder their reading. Key factors emerging from this analysis were (a) difficulty of interesting books, (b) access or lack of access to preferred materials, and (c) access to culturally relevant books. These factors were used to guide a new round of twenty key informant interviews with a different set of students. For instance, I asked, "Have you become confused in a book you decided to read? What did you do about that confusion?" Analysis of these new interviews, folded into the previous interviews afforded the opportunity to determine the strength of the key factors. Similarly, a new factor - time to read - was identified from the second round of interviews and explored in re-analysis of the first round of interviews. For purposes of triangulation, I analyzed the qualitative comments made by students in the community book logs to identify student reasons for finishing or abandoning books and for topical trends in students' preferred reading. I also analyzed previous and ongoing qualitative observational data from daily silent reading times, in particular, student and teacher conversations.

The analysis made clear that particular modifications would be necessary to make the intervention effective for all students. Specifically, despite the vast collection of books made available at the onset of the intervention, students were having difficulty locating their preferred books for a variety of reasons (e.g., need for more books representing diverse cultures; need for immediate access to sequels or books on the same topic). When students had plenty of time to read and could secure the books they desired, they were easily engaged. Also, inexperienced readers in particular were successful when they found books that served their interests and that they could easily read. Furthermore, students across the ability levels were quite strategic in their reading when they faced challenging texts and could overcome dilemmas on their own. An exception was for texts that were written in unfamiliar formats (e.g., flashbacks, multiple narrators).

### **Phase IV: Is the intervention improved by expanding access to books and increasing teacher support for less engaged students?**

Guided by the findings in Phase III, modifications were made to the intervention to expand student access to preferred books and to increase teacher support at the individual level for identifying and making sense of difficult but highly motivating texts. Negative case examples in particular, that is, individual students who were perpetually disengaged, were viewed not as outliers, but as important tools in the fine-tuning of the intervention. Attempts were made to ameliorate the problems, and consequently, to further tweak the intervention to make it more effective for the most students as possible. For instance, for several students who were some of the least experienced readers and who were still experiencing difficulties with decoding, teachers tried out a variety of alternative texts that were accessible, yet still highly relevant. In this process, teachers found that novels-in-verse that still contained contemporary relevant themes were not only accessible and appealing to these students, but also to a range of less experienced readers, as well as highly proficient readers. One such book, *I Heart You, You Haunt Me* (Schroeder, 2008), became widely known among students as the perfect book for

someone who had not previously read a book. Thus, a collection of similar verse novels was developed and read widely by many students.

The effectiveness of the modified intervention was measured by continued frequency counts of behavioral engagement in designated class reading time and new entries in community book logs, and this was accompanied by analysis of anecdotal notes recorded in full class periods. Teachers also identified additional students for key informant interviews, in particular, students who appeared to have changed in their reading habits and dispositions. These twelve additional interviews included questions relevant to the modifications, such as “What has a teacher done recently to help you decide to read or keep reading a book?”

An analysis of these data provided satisfaction that the intervention had been improved substantially by the changes. A listing of categories for factors enhancing engagement, and their increasing frequencies, are included in Table 1.

*Table 1: Cumulative frequency counts for factors supporting engagement*

	Weeks 3-5	Weeks 6-8	Weeks 9-11	Weeks 12-14
Student choice	132	199	285	415
Interest in particular books	101	314	552	696
Access to preferred books	97	285	402	655
Time	31	91	313	388
Peers and teachers as resources	46	118	284	423

Categories for inhibiting engagement, and their declining frequencies, are listed in Table 2.

*Table 2: Frequency counts (non-cumulative) for factors inhibiting engagement*

	Weeks 3-5	Weeks 6-8	Weeks 9-11	Weeks 12-14
Difficulty of interesting books	79	73	55	21
Access to preferred books	118	137	173	131
Access to culturally relevant books	53	39	18	11
Time	21	182	63	45

**Phase V: What are the outcomes of the intervention on students' engagement in reading and for the classroom environment?**

The collection of data ended at the end of week fourteen due to strong evidence for student engagement across all identified categories. Table 3 demonstrates the steady increase in engagement across time and across indicators of engagement.

*Table 3: Frequency counts for evidence of engagement*

	Weeks 3-5	Weeks 6-8	Weeks 9-11	Weeks 12-14
Behavioral engagement during class reading time (individual observational checklist)	485/673 (72%)	505/635 (79%)	582/640 (91%)	627/651 (96%)
Student realizations of engagement	64	130	155	190
Student agency toward engagement	144	202	255	270
Voluntary reading beyond designated time	224	270	273	289
Student-initiated talk about books	43	146	203	241

At the end of the spring semester, students completed the same written questionnaire on engaged reading experiences they had completed at the beginning of the school year. Table 4 provides a contrast between beginning versus end of the end of the school year responses.

*Table 4: Engaged reading questionnaire: Beginning-of-year versus end-of-year responses*

Item	Beginning of year	End of year
Name the title of an engaging book	20%	100%
Description of how teachers have aided engagement	37%	94%
Reading voluntarily outside of school	19%	87%
Advice on what others can do to become motivated to read	44%	99%

Finally, teachers submitted records of books read by individual students across the school year. Teachers' documentations of students' reading indicated that students completed an average of 41.64 books ( $SD = 17.98$ ). The degree of variation in quantity of books can be explained likely in terms of how much students had read prior to eighth grade, as evidenced in qualitative data. For instance, a highly proficient reader who read over 100 books in eighth grade reported to us that she typically read 20 to 25 books each school year. In contrast, a highly inexperienced reader who reported he had been in remedial reading programs all through elementary school explained that although he only read 10 books in 8<sup>th</sup> grade, that was more than he had read in all previous years combined. Thus, the volume of reading accomplished by students was likely related to prior experiences.

To determine the unanticipated effects of the intervention, I conducted a content analysis of all qualitative observational data and student interview data that yielded two additional broad outcomes of the intervention that were not originally intended as goals. First, there was evidence (281 instances) that parents became involved in the intervention, either through purchasing books for home similar to those provided in English class, talking to students about what they read, or reading the books themselves. Second, students articulated (397 instances) that the books they read helped change the way they thought about themselves or about the world. Some of these instances were of students reporting that they began to consider the consequences of their actions, and they began to think more seriously about the implications of risky behaviors, such as drug and alcohol use. Much of this evidence was connected to the themes and issues addressed in the edgy young adult literature students preferred to read.

This content analysis of the data also revealed two specific changes in the instructional environment across classes. First, the boundaries between classrooms became blurred as teachers and students often visited other classrooms to find desired texts or to consult with others on book recommendations or strategies for getting through confusion faced in particular texts. It was often necessary for students and teachers to look to other classrooms to find someone who was an expert on a particular book or genre. Second, classroom talk increased, and in response to that change, teachers modified the physical arrangements of desks to accommodate more interaction. They rearranged desks, which were initially arranged in rows and facing the front of the class, into clusters of four or five with students facing each other instead of the teacher.

#### **4. Summary of the intervention**

The initial intervention designed to increase engaged reading consisted of three primary components: a) providing students access to high interest materials, primarily edgy young adult literature; b) allowing students to regulate their reading, including self-selection of text, self-pacing, and the option to abandon books or continue reading; and c) providing time to read in English class every day. Engineering the intervention to make it effective for all students resulted in the following additional guiding principles for teachers interested in increasing engaged reading among adolescents:

- Expand book collections to include significant access to books with characters representing a range of cultural backgrounds, sexual identities, and life experiences.
- Expand book collections to include a wide range of formats, with a special emphasis on texts that are simultaneously accessible for inexperienced readers and complex in terms of issues and concepts (e.g., verse novels and graphic novels).
- Expand book collections to include access to sequels and books in series.
- Make teacher read alouds of high interest texts and teacher booktalks of new texts a regular activity in English class.
- Provide frequent opportunities for students to talk to each other about their texts and to describe the strategies they used to make sense of difficult texts.
- Capitalize on silent reading times when most students are engaged in reading to problem-solve instances of disengagement with individual students.
- Become experts on a wide range of young adult literature by reading substantially in the books preferred by students.

## 5. Reflections

After the completion of this study, the four teachers involved not only continued the implementation of the intervention, but also made additional modifications as they saw fit to improve its potential to foster engaged reading. Anecdotally, scores on standardized reading tests for this grade level improved considerably and have remained elevated in subsequent years. The teachers have been key agents in the dissemination of the research, presenting the findings and practical insights to local and national audiences. They have successfully collected funding from outside sources for additional books for their classrooms.

Perhaps the most useful yield of the intervention from a research perspective is the theoretical leverage afforded by the changes that took place in the classrooms, along with the unintended positive effects of the intervention and changes in the instructional environment. The constraints on length for chapter such as this one prevent a detailed examination of these unintended consequences, but students' reports that reading compelling, relevant literature did more than motivate them to read is not trivial. Indeed, students reported that their experiences were transformative. For instance, Angelique talked about her experience reading *Identical* (Hopkins, 2008):

"Everybody just judges everybody because of the way they look or act. When I read that book, I thought, it's about seeing the person as they are on the inside. It's not about what they look like. It's about being yourself. That's the kind of relationship I want."

Similarly, teachers' goals (and my own goal) for increasing engaged reading was focused on individual readers at the outset of the study. Students' perceptions on the consequences of their engagement indicated not just growth in reading, but also social, emotional, moral, and individual growth (Ivey & Johnston, 2013). Also, the processes perpetuating engaged reading in these classrooms brought to life the theory that literate practices are not at all an individual enterprise, but instead fundamentally social (Street, 1995), particularly evident in the social networks created by engagement. As such, engaged reading cannot be adequately characterized or measured solely by the three dimensions of engagement (behavioral, emotional, cognitive) previously described in the research literature (Fredricks, Blumenfeld, & Paris, 2004). At the very least, engaged reading in the present study had a strong relational dimension.

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ACTIV -  
Adapted Captioning through  
Interactive Video:  
Cycles of Design Research

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# 13. ACTIV - Adapted captioning through interactive video: Cycles of design research

Anya Evmenova & Brenda Bannan

## Abstract

*This chapter describes design research and development cycles of an innovative technology tool for individuals with special needs. Following the Integrative Learning Design Framework (ILDF), an Adapted Captioning through Interactive Video (ACTIV 1.0) software innovation has been conceptualized, designed, refined, and tested. ACTIV 1.0 can be used to enhance existing academic content-based video clips with numerous adaptations supporting various needs of students with disabilities. The findings of multiple research studies and their implications for the development of the intervention are summarized across ILDF phases: Initial Exploration, Enactment, and Local Impact. Plans for testing in the final phase of Broader Impact of the tool are also discussed.*

## 1. The case of ACTIV 1.0

Driven by legal mandates in the U.S. to access general curriculum and goals to improve educational outcomes for children with various abilities and needs, we have developed Adapted Captioning through Interactive Video (ACTIV 1.0) innovative software through multiple iterative cycles of design research. ACTIV 1.0 allows teachers to upload an existing video clip in any subject area and adapt it with a variety of modifications in order to make it more understandable and accessible for students with disabilities, including those with intellectual and developmental disabilities. The prominent features of ACTIV 1.0 involve automatically generating a time-stamped transcript; editing the transcript; adding regular, highlighted text, and picture-symbol captions; adding visual cues; creating multiple-choice quizzes; and tagging each question to the segment in the video containing the correct answer for easy reviewing.

## 2. Educational problem

Two major laws in the United States on educational provisions, the No Child Left Behind Act (NCLB, 2001) and the Individuals with Disabilities Education Improvement Act (IDEA, 2004), mandate full access and active participation of students with disabilities in the general education curriculum. Schools are held accountable for academic performance of all students, including those with disabilities, which is measured by the adequate yearly progress (AYP) in reading, math, science, and social science (Browder, Wakeman, Spooner, Ahlgrim-Delzell, & Algozzine, 2006; NCLB, 2001). Even those students who cannot participate in the standardized evaluation procedures due to their disabilities and are pursuing an alternate assessment option must target academic curriculum. They are assessed on the modified, yet still challenging, goals appropriate for their abilities and needs carefully aligned with local and statewide standards in all subject areas on age appropriate levels. Thus, the focus of education for students with disabilities has shifted from functional to academic performance (Cushing, Clark, Carter, & Kennedy, 2005; McLaughlin & Thurlow, 2003).

With requirements for challenging curriculum and high expectations, very little research has been conducted on facilitating these requirements. Unfortunately, evidence exists that students,

especially those with more severe disabilities, continue to be educated outside the general education curriculum in the United States (Agran, Cavin, Wehmeyer, & Palmer, 2006). It points out that educators may require assistance in designing instructional activities appropriate for students' special needs to foster their access to the academic instruction (Browder et al., 2007). There is a continuous need for evidence-based interventions that support general curriculum instruction providing appropriate modifications for students with disabilities (Evmenova & Behrmann, 2011). Indeed, while some solutions exist, a majority of current technology products for content-based instruction appears to be either too complex or age inappropriate, especially for older students with intellectual and developmental disabilities (Heiman, 2011; Wehmeyer, Smith, & Davies, 2005). That may cause a problem, given that students are expected to be engaged in the same grade-level academic activities as their peers, utilizing materials typically used in general education (Wehmeyer, 2006).

### **Video instruction**

From the early development of television and video technology, educators have been fascinated with the opportunities provided to students with various abilities and needs (Guldager, 1972). Today, the world of video-based instruction has become more multifaceted and interactive. Consistent with Paivio's (1986) dual channeling theory, video-enhanced instruction utilizes both visual and auditory cues resulting in improved learning outcomes. Some learners succeed in processing visual information while others benefit more from sound or text. The value of video media as a rich source of information allowing students to easily create mental models, thus improving comprehension, has been identified by many researchers (Kroeger, Schultz, & Newsom, 2007). The capacity of video features to focus students' attention on relevant stimuli, repetitiveness, controllability, learning without heavily relying on text, and intrinsic motivation provided by video-based instruction were determined to positively affect the acquisition and maintenance of various skills by students with and without disabilities. Video media has found its application in teaching students with more severe intellectual and developmental disabilities, including autism spectrum disorders and mental retardation. However, with this group of students, videos have been primarily used for teaching functional, behavioral, and social skills (Ayres & Langone, 2005; Bellini, et al., 2007; Shukla-Mehta, Miller, & Callahan, 2010). While demonstrating the potential to benefit students with intellectual disabilities, these studies emphasize the lack of research on the integration of video interventions into content-based education.

### **3. Integrative Learning Design Framework (ILDF)**

Design research aims to progress the development, testing, and implementation of innovative educational practices or technologies. The goals of design research are to generate and validate innovative solutions through the iterative process of identifying problems with practitioners; developing prototype solutions; testing the solutions in appropriate contexts, and refining design principles based on data (Reeves, 2005; Anderson and Shattuck, 2012). The design of the innovative instructional technology tool, Adapted Captions through Interactive Video (ACTIV1.0) program, followed the Integrative Learning Design Framework (ILDF; Bannan-Ritland, 2003, 2009) through the intertwined cycles of development, research, refinement, and usability testing of content-based video instruction enhanced with adapted and interactive features. The ILDF includes the (a) Initial Exploration, when the needs of the intended users are identified through the review of literature and/or problem identification; (b) Enactment of the initial design of the intervention prototype supported by feedback from potential users; (c) Local Impact, the first evaluation phase where the impact of the intervention is tested in a small-scale study(s), and (d) Broader Impact phase, when the adoption of the

intervention by broader audiences is examined. Bannan (2009) provides a full description of the multi-study, multi-method programmatic approach of design research as distinct from a single study (see Bannan chapter in volume A). ILDF phases aim to explore/conceptualize, conduct empirical testing, and systematically incorporate findings into the development of innovative enhanced video technologies for introducing academic content to all students. The ILDF has been applied to other contexts related to children with learning disabilities related to the complexity of the cognitive, motivational and emotional factors prevalent in their learning process (Bannan, 2012). In applying the process to the ACTIV1.0 design research case, a logically ordered, but dynamic iterative framework was based on a series of qualitative and quantitative primary and secondary research studies conducted to utilize the evidence emerged from the data to further guide the design and refinement of ACTIV 1.0. This is an on-going project as we continue to explore the broader impact of the ACTIV 1.0 tool for a larger population.

### **Informed exploration phase**

The informed exploration phase focuses on identification and description of the problem (Bannan, 2009; 2012). In our case a meta-analysis, a descriptive case study, and a review of literature were conducted and analyzed to generate general theoretical perspectives about how students with intellectual and developmental disabilities may be able to learn complex academic content as well as identify design directions corresponding with the theoretical perspectives. Thus, the informed exploration studies provided us with a data-driven rationale and description of potential technology solution.

### **Meta-analysis**

As part of the informed exploration, it was important for us to investigate the effectiveness of the video instruction in general as well as the video medium specifically for students with intellectual and developmental disabilities. So we conducted a meta-analysis of existing literature to answer the following research questions: (1) Is video instruction an effective intervention? and (2) What features of video instruction benefit students with various abilities and needs? (Evmenova & Mastropieri, 2008.) This secondary research study quantitatively synthesized the literature on efficacy of video instruction presented in various formats as an intervention tool for teaching academic, functional, and behavioral skills to school-aged children with and without disabilities in school settings. The main focus of the review was on the areas on instructional content where video was utilized as well as on the different video forms and interactive features commonly used for different students. Video instruction efficacy studies were located by searching the major electronic databases: *PsycINFO*, *Social Sciences Citation Index*, *Educational Resources Informational Center (ERIC & EDRS)*, and *Digital Dissertation Abstracts*. The search was carried out based on the following descriptors: *anchored instruction*, *video instruction*, *videotape instruction*, *interactive video*, *computer-based video instruction*, *video modeling* and *video self-modeling*. Furthermore, a search of selected studies' references as well as tables of contents in relevant journals was conducted to locate additional studies. The studies were included if they met the following criteria: (a) examined video as an intervention; (b) referred to any type of video instruction; (c) included K-12 students with and without disabilities; (d) were dated between 1991 and 2007; and (e) were published in peer-reviewed journals. The studies were excluded if they focused on video instruction for preschoolers, undergraduate/graduate students, teachers, adults; videoconferencing, video games, distance education, higher education, nursing, medicine, sport; position papers; studies with missing data and/or inappropriate visual representations of data that would interfere with meta-analysis coding.

A coding system along with the coding conventions was developed to identify and analyze the effectiveness of video instruction and its factors in each study. Adapted from a coding sheet created by McNeil and Nelson (1991) for their meta-analysis of interactive video instruction, the present coding system included variables in the following areas: Introduction; Sample Characteristics, Intervention Characteristics and Study Outcomes. The effectiveness of a treatment group over a control group in standard deviation units (Glass, McGraw, & Smith, 1981) was calculated using the formula  $ES = (X_{E\ post} - X_{E\ pre}) - (X_{C\ post} - X_{C\ pre}) \div (SD_{E\ post} + SD_{E\ pre} + SD_{C\ post} + SD_{C\ pre})/4$ . The effectiveness of video instruction from single-subject research studies was calculated using the percentage of non-overlapping data (PND) score defined as the proportion of treatment data not-overlapping with baseline data (Scruggs, Mastropieri, & Casto, 1987). PND is a commonly used technique to evaluate the effect size of the intervention in single-subject research studies. A larger PND stands for the higher effectiveness of an intervention. Each study could have several effect sizes or several PNDs based on the number of conditions and dependent measures.

The primary researcher coded the majority of articles. However, throughout the study a random sample (about 15% of all studies included in this meta-analysis) was given to an independent person to make sure she coded them the same way as the researcher. Interrater reliability of coding was 95%.

Seventy-five ( $N=75$ ) studies were located following the rigorous search procedures described above and integrated through a meta-analysis technique. All included studies were published between 1991 and 2007 in 37 different general, special education and technology related journals. Effect sizes for 37 experimental studies and PNDs for 38 single-subject studies were calculated (Evmenova & Mastropieri, 2008). Overall effect size in group studies ( $M=.69$ ;  $SD=.90$ ) yielded the conclusion that video instruction could be relatively effective when working with students with and without disabilities. Percent of non-overlapping data from single subject studies demonstrated that video instruction also moderately effective for teaching students with disabilities ( $M=70\%$ ;  $SD=28\%$ ). In fact, video instruction was found to be more effective for students with moderate disabilities rather than students with mild disabilities or students without disabilities. An additional interesting finding indicated that videos with higher interactivity resulted in better acquisition and retention of the skill (videos with medium interactivity when students interact with the video content but do not receive any feedback as well as videos with high interactivity when video content changes based on the students' input). One of the major findings for the development of ACTIV 1.0 was the fact that while students without disabilities or those with mild learning disabilities primarily watch videos as part of the academic instruction, students with intellectual and developmental disabilities utilize video instruction primarily for learning functional skills and social behaviors.

Currently, these findings still hold true. The most recent video research with students with intellectual and developmental disabilities is focused on integration of video in preparing individuals of different ages for more independent and successful lives. Different formats of video instruction have been used for teaching appropriate:

- social behaviors (e.g., Cihak, Fahrenkrog, Ayres, & Smith, 2010);
- receptive and expressive language (e.g., Mechling & Hunnicutt, 2011);
- imaginative pretend play (e.g., Nikopoulos & Nikopoulou-Smyi, 2008);
- recreational activities (e.g., Hammond, Whatley, Ayres, & Gast, 2010);
- daily living skills (e.g., Van Laarhoven, Zurita, Johnson, Grider, & Grider, 2010) including
  - transportation (e.g., Mechling & O'Brien, 2010),

- grocery shopping (e.g., Hansen & Morgan, 2008),
- cooking skills (e.g., Ayres & Cihak, 2010), and
- employment tasks (e.g., Mechling, 2008).

Indeed, only a few studies utilized video-based instruction for teaching students with intellectual and developmental disabilities such skills as sight word recognition (e.g., Lee & Vail, 2005), reading fluency, comprehension (e.g., Hitchcock, Prater, & Dowrick, 2004), and spelling (e.g., Kagohara, et al., 2012). However, most of the aforementioned studies focused on preschool and elementary level students with mild intellectual disabilities. So the question remained why video instruction being relatively effective was not geared more towards teaching academic skills to students with intellectual and developmental disabilities.

### ***Qualitative study***

In order to fill the gap in research about the best environments for video integration with students with disabilities, we conducted a small descriptive case study to answer such research questions as: (1) How stakeholders, teachers, integrate video clips into academic content lesson plans?; (2) How they design and create supplementary activities adapted to the needs of students with intellectual disabilities? and (3) What past experiences and current perceptions do teachers have about using video with this population? Thus, the overarching purpose of the study was to explore teachers' experiences and perceptions as well as the process of integrating video in content-based academic instruction for students with intellectual and developmental disabilities.

Semi-structured topical interviews were conducted with four teachers, who were selected through convenience sampling based on the criteria: (a) teachers of students with intellectual disabilities; (b) must use video regularly for the instruction in academic/content areas and (c) must use video regularly (at least once a month, preferably more frequently). The invitation was sent out to members of three listservs. However, only four teachers agreed to participate. Several plausible explanations for the low number of responses included: teachers not having had the time for a 60-minute interview- or not choosing to respond for reasons such as spring break vacation. However, it is also possible to presume that there were no additional teachers who used video for teaching academics to students with intellectual and developmental disabilities even in such a large pool of educators.

So, the data for this study was generated from interviews with four special education teachers, who teach students with intellectual disabilities and use video on a regular basis in the content areas instruction. In addition, researcher's memos and teachers' lesson plans throughout the data collection and analysis were incorporated into the process. The data were analyzed using the open and axial coding of the constant comparative method (Merriam, 1998). The particular incidents were compared within and across transcripts, lesson plans, and researcher's memos. Thus, the trustworthiness of the study was increased through triangulation of data.

Through the study we learned how video could be incorporated into instruction in multiple ways. We found that teachers showed it in all the areas: literacy, math, science, and social studies. The overarching use of the video was to introduce the academic topic or to "launch instruction." Every teacher stressed out the necessity to stop video at times to review the content. This finding is corroborated by the research on video use with students with high-incidence disabilities (Serafino & Cicchelli, 2003). The major difference is the length of the segment before discussion.



While students with less severe learning disabilities can attend to longer video clips, teachers in this study preferred to see shorter clips. Furthermore, we learned that teachers supplemented video clips with paper-based and hands-on activities. Those took place either during or right after the video clip. "I might make a little worksheet. Make it something interesting. Word search or fill out, crossword; something easy that they can handle." In addition, teachers used several picture-based software programs such as *Boardmaker* and *Writing with Symbols* to supplement video content. Both the video chunking and the use of picture symbols were later incorporated into the ACTIV 1.0 tool.

Three major themes emerged from the data supported by the participants' direct quotes: (1) "video is not a panacea; it's just an alternative avenue" to provide access to content information; (2) "video is an enhancement to instruction, not replacement"; and (3) "video for students with disabilities must be short, purposeful, understandable, as well as age and developmentally appropriate". Indeed, a criterion for choosing videos was "so they would be able to understand it." It appeared to be critical to find materials that would not talk "about things beyond their vocabulary." With this population it is important to ensure that "film has a purpose." However, "it is hard to find a video that holds their attention that is also age appropriate for a child in a high school aged body."

These findings were supported by the meta-analysis results on video instruction for various students described earlier. Thus, the qualitative study allowed to locate the problems associated with introducing content to students with disabilities via videos. It became imperative that existing academic videos must be adapted to be successfully used by students.

### ***Theoretical framework***

The search for the possible adaptations to improve students' comprehension of complex academic videos brought us back to the literature. Several suggestions for video adaptations were considered.

### ***Closed captions***

One of the most commonly used strategies for improving comprehension and retention of video content is closed captioning (or subtitling). Despite the fact that closed captioning was originally designed to provide access to audio and video materials for people who are deaf and/or hard of hearing, it has found alternative applications in introducing and reinforcing reading skills to young children, adults, English language learners, and students with learning disabilities (Bowe & Kaufman, 2001; Nugent, 2001). Captions add invaluable support for viewing and understanding of video.

Despite the argument of distractibility, closed captioning was also determined to be an effective and, in most cases, unobtrusive strategy for teaching reading to students at risk or with learning disabilities (e.g., Meyer & Lee, 1995). The initial attempt to determine the impact of embedded textual prompts resembling captioning into video recordings for children with autism resulted in relative improvements (Reagon, Higbee, & Endicott, 2007). Indeed, print and television obviously complement each other creating multi-sensory environments for motivational learning through auditory, visual, and written cues (Linebarger, 2004).

### ***Dynamic highlighting***

The benefit of redundancy in the presentation of content via visual (e.g., captioning) and auditory (e.g., soundtrack) stimuli may be enhanced more when combined with synchronized highlighting of the captions along with the narration.

Thus, each word is highlighted as it is being spoken out. When compared to typical closed captioning options, it was anticipated that the highlighted text captions might have the potential to better attract students' attention and increase comprehension, especially of those students who could read (Hecker et al., 2002).

### ***Picture symbols***

An additional example of an adaptation shown to be effective with students with intellectual and developmental disabilities is incorporating picture symbols as a visual enhancement. Some students with intellectual disabilities may experience difficulties reading even simplified text, so captions should be further adapted to include picture symbols associated with each word. Picture symbols have been successfully used for providing access to printed materials to those individuals with severe reading difficulties (Detheridge & Detheridge, 2002; Slater, 2002). Interventions including picture symbols allowed children with disabilities to easily generalize their improved performance into new environments and demonstrated long-term retention of newly acquired skills (Preis, 2006). In fact, participants with lower reading comprehension levels appeared to benefit more from picture symbols than stronger readers (Jones, Long, & Finlay, 2007). Therefore, picture-based captions might support students with disabilities understanding of the video content, anchoring their factual and inferential comprehension of the video content in easy to understand line drawings (Walker, Munro, & Richards, 1998). In addition, they might anchor their comprehension and aid in the retention of the video content.

### ***Interactive videos***

Interactive elements transform passive video viewing by facilitating and empowering students' active engagement in the learning process (Lee & Vail, 2005). Active engagement includes an additional dimension of action to icons and words already existing in the video format. This provides three forms (actions, icons, and words) of representation for the same material essential for successful computer learning resulting in increased value of the video (Bruner, 1966; Presno, 1997). While there are only few studies that have integrated interactive videos with students who have intellectual and developmental disabilities, these interactive features were found to be effective. Students demonstrated an improved performance using videos in purchasing and job acquisition skills, paying bills, selecting photographs of the appropriate job steps, and moving through the store, which required individuals to interact with onscreen elements embedded into video-based computer programs (e.g., Ayres et al., 2006; Mechling & Ortega-Hurndon, 2007). Moreover, enhanced videos, designed to incorporate interactive elements, appear to contribute even more to increases in students' achievement. In fact, the meta-analysis described above suggests that students' performance improves as the levels of interactivity and physical engagement within the video-based program increase. Based on the existing literature, it was possible to hypothesize that students with intellectual and developmental disabilities might be able to participate and benefit from interactive features such as searching content-based videos for information.

Overall, the development of ACTIV 1.0 integrated a number of theories. Thus, strategies that have demonstrated to be effective for students with disabilities, including video format, closed captioning, dynamic highlighting, and interactive computer-based features, were incorporated into the content and standards-based academic instruction provided through ACTIV 1.0 tool.

### **Enactment phase**

Enactment phase allows the initial design of the educational intervention in response to a particular education need or problem (Bannan, 2009; 2012). All knowledge acquired in the previous phase was incorporated into the development of the initial prototype of video adaptations as well as the ACTIV 1.0 tool.

### ***Original experimental study***

Guided by the results of the informed exploration phase, as well as by the review of existing literature, the effectiveness of various types of captioning (highlighted text and picture/word-based captions); alternative narration; and prompted interactive video searching on the factual and inferential comprehension of non-fiction academic videos was examined. A single-subject/case multiple baseline study was conducted with 11 postsecondary students with intellectual disabilities to answer the research question: Will students with intellectual disabilities increase their comprehension of video content enhanced with various adapted and interactive features? This investigation focused on better access and successful participation of learners with disabilities in the general education curriculum (Evmenova, 2008; Evmenova et al., 2011; Evmenova & Behrmann, in press).

The 11 participants from the postsecondary program for young adults with intellectual and developmental disabilities at a major mid-Atlantic university included 5 male and 6 female students (age 19-25; IQ 40-70). Participants were chosen based on the criteria: (a) enrolled in the postsecondary program for individuals with intellectual disabilities in 2007-2008; and (b) agreed to participate by providing the personal informed assent/consent. Furthermore, participants' prerequisite skills included: attention to a task for at least 15 minutes; ability to orally respond to a question; visual ability to view video images; auditory ability to hear questions and follow verbal directions; and motor ability to select hyperlinks in the program using a standard mouse.

The potential promise of the adapted and interactive videos for increasing student achievement outcomes in content areas was examined through repeated measurements of single-subject/case research designs. A single-subject/case is one of the experimental research methods common for the field of special education. While it usually includes small samples ( $N > 1$ ), the experimental control is achieved through repeated measurements of each participants' behavior in different conditions (see Kratichwill et al., 2010 for more information about single-subject/case experimental research methods). In multiple baseline design, after 3-5 sessions in the baseline condition, the researcher introduces the first randomly assigned participant to an intervention, leaving the rest of the participants in the baseline. After the next few sessions, the researcher introduces the second randomly assigned participant to an intervention. The process continues, so that each subsequent participant is introduced to the treatment in a staggered fashion. Thus, the improvements in comprehension were expected only when students were introduced to adapted and interactive videos, while remaining at baseline level prior to introduction to intervention.

Data were collected across 41 observation sessions. Participants were asked to watch the video (either regular or adapted) and answer 3 factual and 3 inferential questions about the video content. Videos were aligned with the Virginia Standards of Learning (SOLs) and presented content on current issues (e.g., president elections, hurricanes, global warming, obesity, texting while driving, etc.). Adapted videos included highlighted text and picture symbol verbatim captions, alternative narration, and interactive searching of video for answers.

Interobserver agreement and fidelity of treatment data were collected during 33% of sessions and were 89.5% and 100% respectively. Answers to comprehension questions were graphed on a line graph in both baseline and treatment conditions. A special statistical analysis of the single-subject data (with small number of participants), a randomization test, was conducted to identify the statistical significance of findings. The randomization test is based on the null hypothesis that there would be identical responses across repeated measurements if the baseline and treatment conditions were presented in a different order at different times. The actual mean difference between baseline and treatment conditions is determined and compared to the mean differences of thousands of data permutations across phases. The proportion of permutations larger than the actual mean difference determines the probability or statistical significance of the intervention (Dugard, File, & Todman, 2012; Edgington & Onghena, 2007). In addition, social validity interviews were conducted with the students.

The visual analysis of single-subject/case data across participants allowed to conclude that (a) all 11 students significantly improved their factual comprehension of non-fiction video content after viewing adapted videos and 8 out of 11 students demonstrated a modest increase in their inferential comprehension; (b) both factual and inferential comprehension across all 11 participants significantly improved further after students had an opportunity to search the video for answers and adjust their original responses; (c) the majority of participants performed equally well regardless of the type of captions (e.g., highlighted text captions or picture symbol based); and (d) students enjoyed watching and interacting with adapted videos and found them very helpful. The results of this study are presented in detail elsewhere (Evmenova, 2008; Evmenova et al., 2011; Evmenova & Behrmann, in press).

One of the most important practical findings was that despite promising results, it would be too time consuming and labor intensive for teachers to adapt existing videos with various modifications. Thus, an easy-to-use video enhancement program, such as ACTIV 1.0, is needed to support the effective and efficient use of the adapted and interactive videos.

### ***Expert panel review***

The ACTIV1.0 storyboard has been conceptualized based on what was learned through previous studies. After the prototype of the instructional technology had been developed with the support of the external funding (USDOE Steppingstones of Technology grant funding (CFDA 84.327A), an expert panel review was implemented (Evmenova & Graff, 2012). The main purpose of the expert panel review was to answer the following research questions: (a) Are the components of ACTIV 1.0 software appropriate and beneficial for teaching students with disabilities?; and (b) Is ACTIV 1.0 interface user friendly allowing to easily adapt existing video clips? This was a qualitative, observational interface testing study. The initial version of the ACTIV1.0 prototype was reviewed by the panel of six experts, including technology specialists, school-based special educators, experts in the area of content-based instruction and instructional design. Qualitative data were collected via observations while using ACTIV1.0; expert checklists; and interviews to compile the list of possible revisions for the video tool.

Experts were asked to (a) select and upload a video; (b) enable automatic transcript creation; (c) view the video with highlighted text and picture symbol-based captions; (d) check transcript for accuracy and make necessary changes; (e) explore transcript's automatically created time stamps; (f) create key word captions; (g) develop their own transcript by deleting and changing words; (h) add a visual cue; (i) create a multiple-choice quiz embedded in the video; (j) tag appropriate video segments to each quiz question; and (k) take a quiz and preview the video

segments. Participants were asked to consider the overall ACTIV 1.0 program quality including (a) usefulness of the product to students with disabilities; (b) accessibility (508 compliance) of the tool for users with disabilities; (c) overall ease of use and user friendliness. The observations focused on the ability of experts to complete the task independently; time it took to complete the task; number of hits to do the task; number of errors before completing the task; number of times experts referred to the manual or asked for help. Interviews explored overall perceptions of the panel in terms of ACTIV 1.0 usability and interface.

Overall, all participants saw a great potential in using ACTIV 1.0 tool to adapt videos for students with disabilities. The observational, questionnaire, and interview data from the expert panel review of ACTIV1.0 were analyzed to compile the list of recommendations and to steer further development of the technology innovation. The list of revisions and adaptations was divided into (a) functional changes and (b) interface changes. Thus, an example of the functional change would be to incorporate the data collection feature on mouse clicks generated by the program or to continue working on the text-to-speech feature aiming for synchronization between text-to-speech and video. Some of the interface changes included rearranging the interface to include large bold headings or show fewer words per captioning line in a larger font. Overall, the multiple data sources from enactment phase were integrated to finalize the conceptual design of the prototype. Iterative revisions to the ACTIV1.0 were implemented as a result of feedback received from those studies.

### **Local impact phase**

Local Impact phase guides the initial testing and formative evaluation of the technology prototype to further understand the ways to support academic instruction for students with disabilities (Bannan, 2009; Bannan 2012). A number of small scale experimental studies were conducted in this phase.

### ***Local impact experimental studies***

Local impact of the technology innovation was determined through the usability testing of adapted videos created with the ACTIV1.0 tool for middle and high school students with intellectual and developmental disabilities. Small scale testing was conducted using single-subject/case research methodology with embedded randomization. Overall, three multiple baseline and alternative treatments studies were implemented in one science and two social studies classrooms to answer the overarching research question: Will students with intellectual disabilities increase their comprehension of science and social studies content after watching adapted and interactive videos? (Evmenova & Graff, 2011).

The usability testing of videos created with the ACTIV1.0 tool was conducted with four middle school students (age 13-14) in science; four middle school students (age 13-14) in social studies; and four high school students (age 16-20) in the transition classroom. Participants were purposefully selected from self-contained classrooms for students with intellectual disabilities to include those who (a) used video for academic instruction on a regular basis; (b) regularly used picture symbols; and (c) received regular instruction in language arts, science, and/or social studies. Participants had to have similar prerequisite skills as in the original experimental study described above, which included the ability to see, hear videos as well as manipulate the standard mouse.

The usability testing focused on comparing regular and adapted videos in science, social studies, and transition across baseline and treatment phases across 15-18 sessions.

In addition, possible outcomes of various adapted and interactive video features were determined: highlighted verbatim vs. key word captions; picture-symbol verbatim vs. key word captions; searching the video for answers. Videos topics included Civil War for middle school science; Snakes and Lizards for middle school social studies; and Transportation for the high school transition classroom. Participants' performance on the comprehension test was collected with the data collection feature built into the ACTIV 1.0 prototype. Students' correct responses to six comprehension questions were graphed for the visual analysis of data. Interviews with teachers and students were used to consider social validity of ACTIV 1.0 and any additional revisions of adapted videos. Interobserver agreement and fidelity of treatment data were collected during 25% of all sessions and were 98% and 100% respectively.

All participants displayed improvements in comprehension after reviewing captioned video segments. On average students improved from  $M=1.6$  ( $SD=.4$ ) to  $M=4.9$  ( $SD=.7$ ) in middle school science; from  $M=1.8$  ( $SD=.8$ ) to  $M=4.9$  ( $SD=.7$ ) in middle school social studies; and from  $M=1.7$  ( $SD=.4$ ) to  $M=3.9$  ( $SD=.7$ ) in high school transition. In addition, there was no visible difference between verbatim and key word captions. Additional findings were based on the students' interviews conducted at the end of the study as well as the direct observations of the participants. All students enjoyed learning science, social studies, and transition through interacting with adapted videos. However, due to the fact that the video narration level was not adjusted like in the original experimental study, captions were presented at the rate and the level of the original narration that was relatively high. Students noted the difficulty of the vocabulary saying that, "Some words were really hard to understand." Observation notes revealed that the participants might not have had an opportunity to look at the captioning window due to high narration rate. Therefore, further development of ACTIV 1.0 is possible to allow adapting video narration vocabulary level and the rate to match students' abilities and needs.

#### **Plans for investigating broader impact**

Up to date, the results of this design research project included the use of the ILDF to guide the development, refinement, and testing of the innovative instructional technology, ACTIV 1.0. Through Informed Exploration, Enactment, and Local Impact phases that incorporated intertwined qualitative and quantitative studies, the final ACTIV1.0 prototype was developed. ACTIV 1.0 allows teachers to:

- Upload any existing video (Figure 1).
- Automatically create a transcript (using speech-to-text mechanisms) with time stamps added to each word (Figure 1).

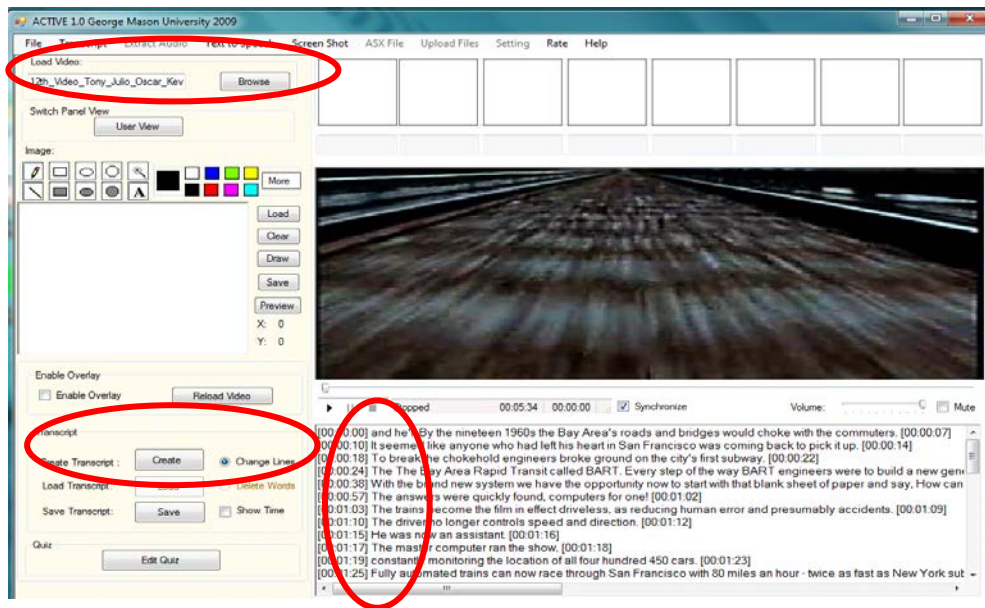


Figure 1: Uploading any existing video, automatically creating a transcript with time stamps added to each word in the existing ACTIV prototype

- Add verbatim closed captions with each word automatically highlighted as it is being spoken aloud (Figure 2).

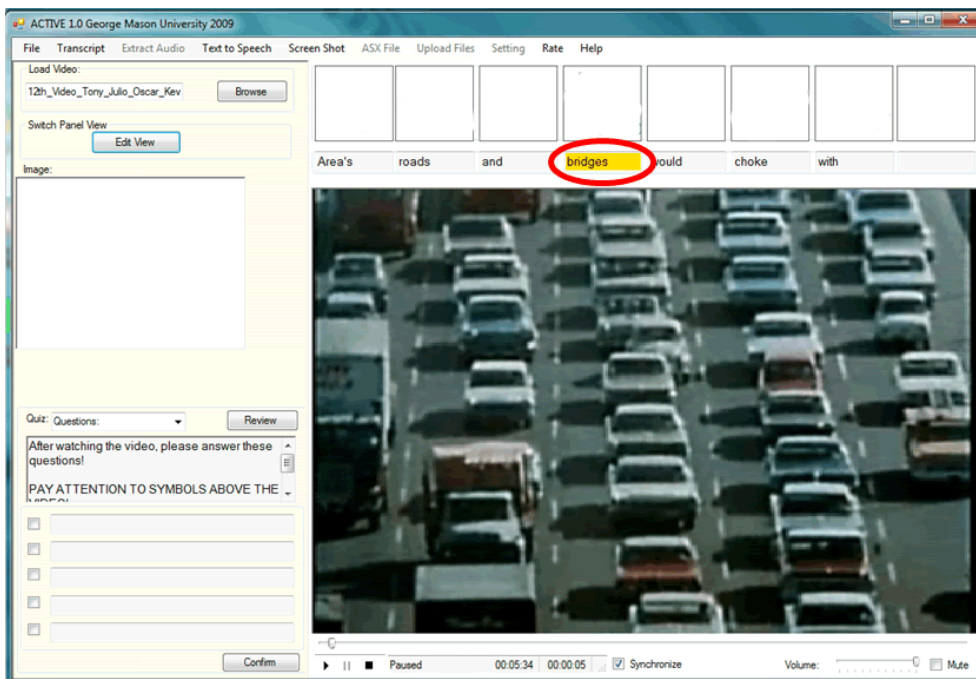


Figure 2: Adding verbatim closed captions with each word automatically highlighted as it is being spoken aloud in the existing ACTIV prototype

- Automatically add picture symbols from Symbolstix to each word in captions (Figure 3).

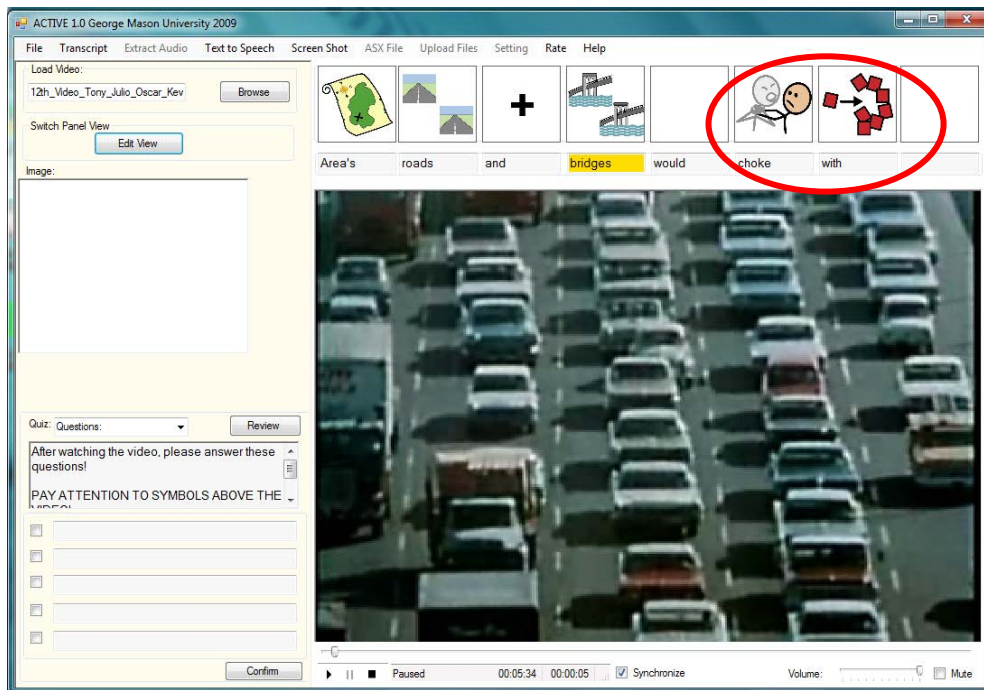


Figure 3: Automatically adding picture symbols from Symbolstix to each word in the captions in the existing ACTIV prototype

- Edit text in the transcript to improve accuracy and to create key word captions (Figure 4).

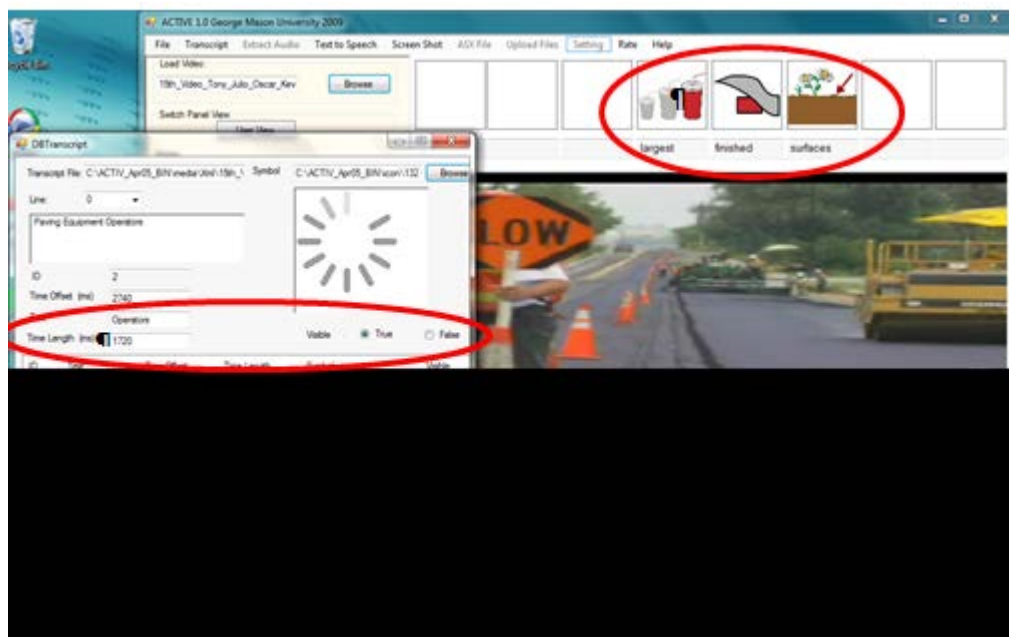


Figure 4: Editing text in the transcript to improve accuracy and/or to create key word captions in the existing ACTIV prototype

- Add visual cues to the video to focus user's attention on important stimuli (Figure 5).



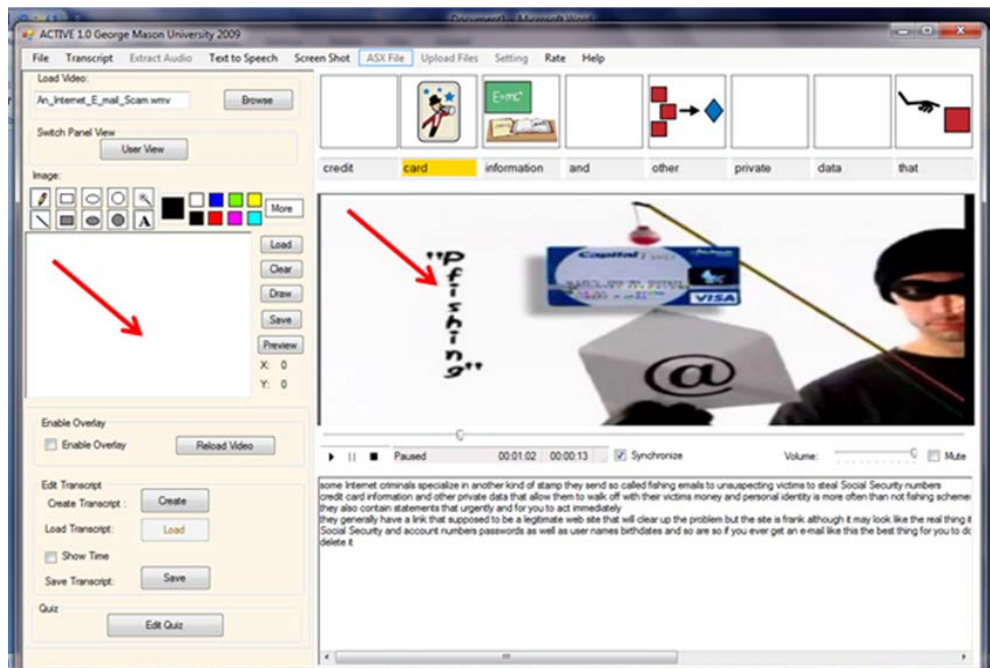


Figure 5: Adding a visual cue to the video screen to focus user's attention on important stimuli in the existing ACTIV prototype

- Create multiple-choice or true/false comprehension quizzes (Figure 6).
- Tag each question to the segment in the video, so that the user can review/watch that segment which contains the correct answer to the question (Figures 6 and 7).

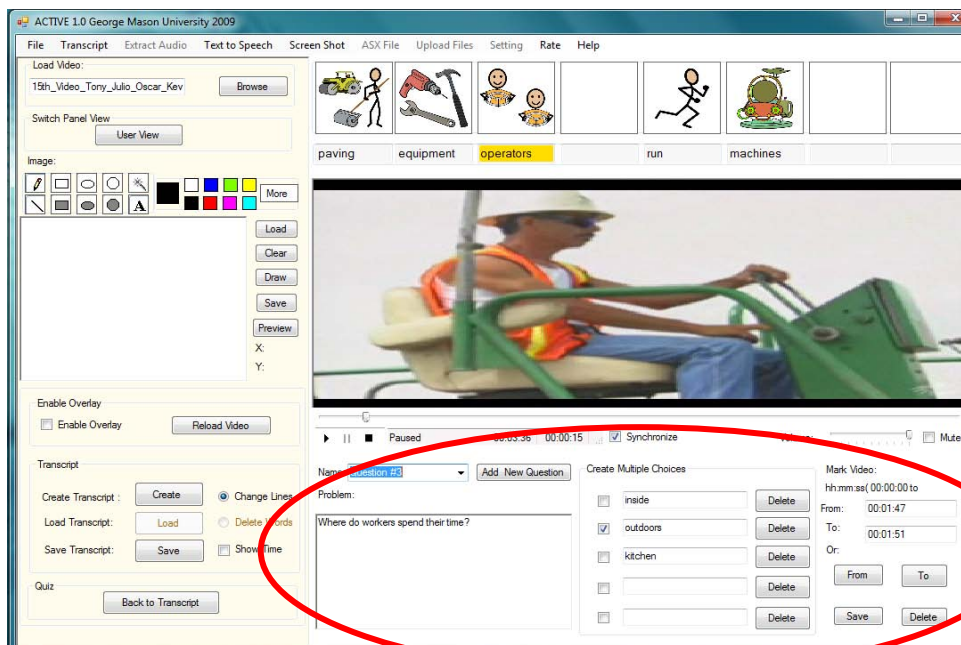


Figure 6: Creating multiple-choice or true/false comprehension quizzes and tagging each question to the segment in the video containing the correct answer in the existing ACTIV prototype

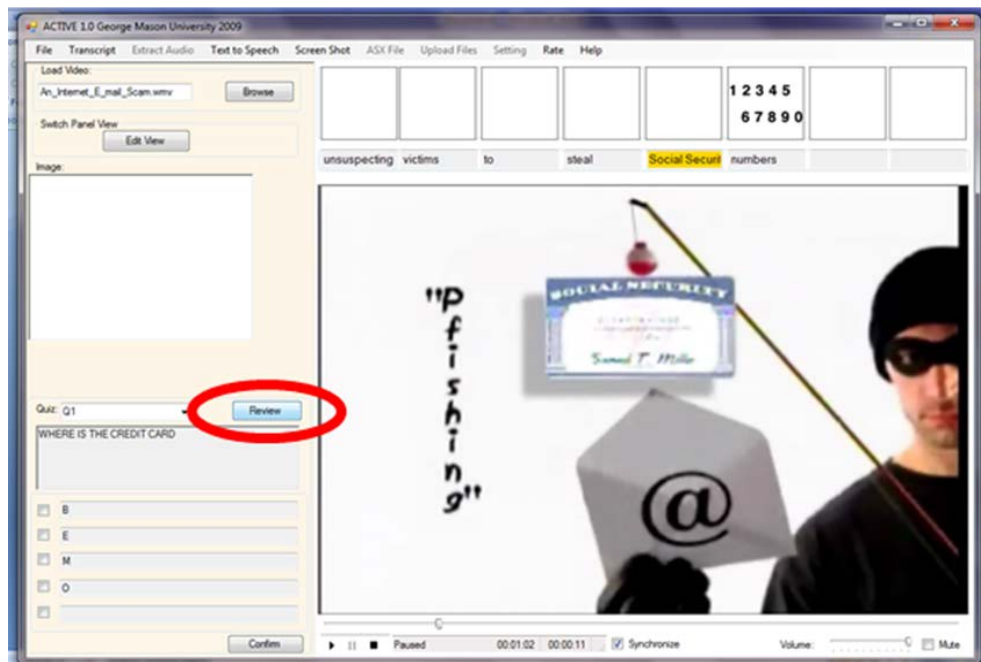


Figure 7: Allowing users to review/watch the segment in the video containing the correct answer to the corresponding comprehension question in the existing ACTIV prototype

- Collects mouse-click data on the interactions with the program.

All previous research allows better understanding of the variables and contexts preparing for additional testing with larger groups of students. We hope to explore the Broader Impact through large-scale quasi-experimental or randomized trials research studies not limited to students with intellectual disabilities in the nearest future.

### Summary

Overall, ACTIVE1.0 offers great practical significance providing additional, technology-based support to provide accessible academic content to students with and without disabilities. In addition, the use of content-based videos enhanced with adapted and interactive features contributes to theory and knowledge in the field of effective teaching, technology solutions and media strategies. Finally, this project demonstrates the scientific significance and implementation of design research. Overall, the following steps constituted this design research study. First, the informed exploration of this technology-based intervention was conducted through: (1.1) a meta-analysis of the existing literature on the overall effectiveness of video format as an educational intervention as well as the effectiveness of various video features for students with different abilities and needs; (1.2) a qualitative exploratory study to understand teachers' experiences and perceptions of integrating video in content-based academic instruction for students with intellectual and developmental disabilities; and (1.3) a review of existing literature to identify possible adaptations to improve students comprehension of complex academic videos. The enactment phases included (2.1) a single-subject multiple baseline study with 11 postsecondary students with intellectual disabilities to investigate whether adapted and interactive videos could increase students' comprehension of video content; and (2.2) a qualitative, observational usability testing study conducted with the experts to identify the necessary changes to the program interface. In turn, local impact of the technology intervention was determined through (3.1) a single subject study with 4 middle

school students with intellectual disabilities in science; (3.2) a single subject study with 4 middle school students with intellectual disabilities in social studies; and (3.3) a single subject study with 4 high school students with intellectual disabilities in social studies. Thus, utilizing different research methods, ACTIV1.0 innovative tool was developed through the iterative, data-driven design process resulting in new knowledge about teaching and learning. Thus, easily created adapted videos may enhance and reinforce high-quality content-based general education instruction for all students.

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## Teachers Engaging in Mathematics Design Research

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# 14. Teachers engaging in mathematics design research

Michelle Stephan & Paul Cobb

## Abstract

*In this chapter, we describe a Design Research Project that was conducted over a five year period by a team of teacher/researchers in a middle school setting. This five year project falls under the category of Classroom-based Design Research in which the aim is to create an instructional sequence and conduct several cycles of design, implementation, and analysis with the result being a stable instructional theory for a particular mathematical topic, in this case integer addition and subtraction. We use this particular case to situate the more broad goals, purposes, and methodology associated with Classroom-based Design Research.*

## 1. Introduction

The goals of educational research can be as diverse as the methods for conducting it. Design Research is one such method that has recently come to prominence in mathematics and science education research. Its appeal lies in the fact that, while much educational research is divorced from practical problems, Design Research is necessarily located in the practical settings of which it is designed to study. While design research can be conducted at a range of levels (Cobb, Confrey, DiSessa, Lehrer & Schauble, 2003), the work we report here is classroom-based research (Cobb, 2003) in which an instructional design was tested, analyzed and revised on a daily basis by several teachers in their classrooms. Our chapter documents the activities and results of a group of teachers who worked over a five-year period to design, test and revise an instructional sequence to support middle grade students' (12-14 year olds) development of addition and subtraction with integers (i.e., positive and negative whole numbers). Their work can be distinguished from action research in that the primary intent of their research was to contribute to the development of an instructional theory that could be used in their classrooms and adapted by other teachers.

Design research is usually motivated by university members with experience and interest in building theory and instructional designs. Typically, the teacher is considered as a member of the research team, with the primary responsibility of implementing instruction. However, in this chapter we elaborate on Design Research that was conducted by a team comprised mostly of classroom teachers whose primary interests involved improving their teaching practice and students' mathematical reasoning. Their goal was to create a stable instructional unit for integer addition and subtraction that they could use to help students learn the topic with meaning. The team was led by the first author, one of the middle-school teachers, who had previous experience in conducting Design Research at the collegiate level, but who had left the university and was teaching full time in a public school. Since her full-time job was now middle-school mathematics teaching, her primary commitment was towards instruction, not necessarily research. However, with her background in Design Research, coupled with her commitment to teaching, she was able to lead her colleagues through the necessary steps to conduct legitimate and successful Design Research.

The goal of this chapter is to elaborate the steps that this community of teacher researchers took to engage in Design Research, provide the reader with the outcomes of five years of research, and to discuss the lessons learned as they struggled to conduct rigorous research while teaching full time.

## 2. Why integers?

Integer concepts and operations is an extremely difficult content area for most students to learn with meaning (Gallardo, 2002; Glaser, 1981; Vlassis, 2004, 2008) since integers is arguably the first mathematical object that cannot be represented physically. Additionally, research indicates there is no agreed upon method for teaching integers conceptually. The textbook that had been adopted by the teachers' school did not support students learning integer operations with meaning, so Stephan and her co-teacher<sup>1</sup> decided to design their own instructional sequence. Their motivation was primarily pragmatic in that their prior students merely memorized the rules for operating with integers, but the lack of a strong instructional sequence for teaching integers was a theoretical motivation for Stephan. Using the instructional design theory of Realistic Mathematics Education (Gravemeijer, 1994; Stephan, Bowers, Cobb & Gravemeijer, 2003), they created a first draft of a sequence that used assets and debts as the realistic context for exploration. Four years later, a total of six teachers were implementing a relatively stable instructional sequence that resulted from several cycles of Design Research.

Since the "research team" consisted of middle school teachers, they did not have adequate resources to conduct Design Research at its most sophisticated level initially. For example, the first classroom experiment consisted only of Stephan and her co-teacher with little time for reflection during the school day and no official data collection other than student work and field notes to document student thinking. However, as more colleagues joined their efforts and administration began recognizing their work, rigorous data collection and analysis became possible.

## 3. Why design research?

Engaging in cycles of implementing, assessing and revising an instructional unit that could support students' learning integers with meaning is particularly well-suited for Design Research. Research on teaching and learning of integers shows that there is no one, clear instructional theory on integers; thus, the iterative cycles of Design Research provides guidelines for teacher researchers to design, implement and analyze the effect of their instruction over the course of time. Their inquiry was more naturalistic in that they wanted to investigate the means by which they would support their students' learning and their instruction more generally.

Their Design Research can be cast as a validation study (Plomp, 2009) in which the teachers attempted to design and validate an instructional theory for integer addition/subtraction through a series of classroom teaching experiments (Cobb, 2000). Their research was shaped by two questions and one main outcome:

Question 1: Can finance serve as a valid context for learning integer addition/subtraction with meaning?

<sup>1</sup> A co-teacher is a teacher who is certified to work with students who have a variety of learning disabilities. A co-taught classroom is one that is comprised of both regular education students and those with disabilities and is assigned both a regular and special education teacher.

Question 2: Can a linear model with a vertical number line serve as a strong inscriptional support for students' reasoning?

Intended Outcome 1: An instructional theory for integer addition/subtraction that can be adapted by teachers

In the remainder of this chapter, we describe the various phases of engagement with Design Research that led to the development of a stable instructional theory and associated instructional sequence for integers. A Design Research Cycle consists of three phases at the global level (see Figure 1): Design phase, Implementation phase, and Analysis phase. In the *Design Phase*, researchers typically conduct a thorough literature review to see what progress, if any, has already been made on the topic of interest. In the case of classroom-based research, an instructional sequence is created by conducting a thought experiment to envision how the theory will be implemented in practice. In the second phase, the *Implementation Phase*, the classroom teaching experiment is carried out, with data being collected for subsequent analysis of student learning as well as the means of supporting student development. Data typically consists of student interviews, video tapes of all classroom sessions, and copies of student work. Gravemeijer (2003) notes that the three phases of Design Research described here are actions taken at a global level over the life of the experiment. However, during Implementation of a classroom teaching experiment, there are also daily mini-cycles of design (of a task or tasks), implementation with students, and analysis in order to make changes to instruction in real-time. For example, the teacher researchers met each day to *analyze* student thinking and *design* instruction the subsequent day. Finally, the *Analysis Phase* consists of analyzing the data collected during implementation to make some conclusions about the viability of the instructional theory as well as revisions that should be made in the subsequent Design Phase.

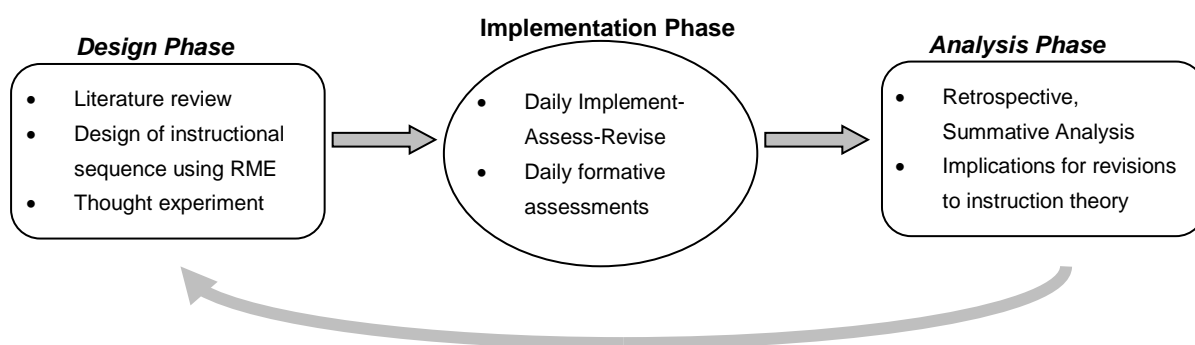


Figure 1: The design research cycle

This research consisted of five, consecutive Design Research Cycles as depicted in Figure 1. Rather than describe the three phases for each of the five years, we will first present the *initial* preliminary design that occurred at the beginning of Year One. We elaborate the *first* preliminary design phase by addressing issues such as the research literature, the theoretical basis for designing instruction, and a prototype instructional sequence. We then turn to the Implementation Phase and integrate the findings over all five years of implementation. Finally, we turn to the Analysis Phase where we elaborate the findings from the entire Design Research program and discuss lessons learned.

#### 4. Preliminary design of the integer design research program

The preliminary design phase reported in this section describes the activities conducted at the beginning of our five year project. Rather than describe the preliminary design phases for each of the five years, we begin with the first year, the most intense work, and give more detail about each year in the implementation portion of the chapter.

##### Literature review

As Plomp (2009) stresses, the preliminary phase of Design Research must search for and build on the prior research in the particular area of study. Several articles detail the struggle that mathematicians had with integers historically, particularly with what it means to go below zero (Gallardo, 2002; Hefendehl-Hebeker, 1991). Attempts to devise instruction on integer concepts and operations have been no less troublesome. Many researchers have interviewed and surveyed students and conducted teaching experiments (Steffe & Richards, 1983) as a way to document students' conceptions of integers from very early ages (Bofferding, 2010) to secondary school (Gallardo, 2002; Vlassis, 2004, 2008). By their very nature, negative numbers cannot be modeled with physical objects and have been labeled "fictive" (Glaser, 1981). Five minus two, for example, can be modeled with five counters and removing two. However, when posed with the problem  $2 - 5$ , young students struggle with taking 5 away when there are only two counters at the start. Additionally, positive and minus signs can take on dual roles in that sometimes the minus sign, for example, may signify a process (subtract), while at other times it is a mathematical object (negative).

In the last 20 years, research has shown that grounding students' work in carefully chosen real-world contexts can be an instructional support to the process of abstraction (De Lange, 1987; Gravemeijer, 1994; Stephan, Bowers, Cobb, & Gravemeijer, 2003). Given the abstractness of the negative number, Janvier (1985) attempted to use helium-filled balloons and sandbags as a context, with balloons raising and sandbags lowering a basket. Along the same lines, Davis (1967) developed a context around debts, with a postman who delivered checks and bills to a housewife who kept track of her money. To help students understand " $-$  ( $-$ )", the scenario involved "mis-delivering" bills and collecting them from the housewife. Schwarz, Kohn and Resnick (1993/1994) criticized both of these contexts as being too artificial for students. Schwarz et al. also criticized using assets and debts (Davis' context), despite Mukhopadhyay, Resnick and Schauble's (1990) findings that children are drawn to using assets and debts as a foundation for negative numbers.

Other contexts that have been explored include positively and negatively charged particles (Battista, 1983), the activities of patrons in a disco (Linchevski & Williams, 1999), passengers on a bus (Streefland, 1996), lengths of positive and negative trains (Schwartz et al., 1993/1994), LOGO turtles moving along a horizontal number line (Thompson & Dreyfus, 1988), and a two-colored chips scenarios (Lytle, 1994; Semadeni, 1984; Smith, 1995).

Research also indicates that there are two bases of imagery that have been explored for supporting students' integer explorations: *neutralization* and *linear* imagery. The positively and negatively charged particles is one example that utilizes *neutralization imagery* where positive and negative charges are treated as zero sum pairs and cancel (or neutralize) each other. For instance, if the problem were  $5 + - 10$ , a student would place 5 positive chips on a mat, add 10 negative chips to the mat and realize that five positive and five negative chips sum to zero (i.e., neutralize each other) leaving the student with 5 negative chips ( $-5$ ) as an answer.

The *linear imagery* makes use of students' reasoning with a number line. The student would place a mark at +5 on the number line and then add ten steps in the negative direction, landing at -5.

These contexts and foundational imageries have shown promise for helping students to create more meaning for addition of integers, with neutralization showing slightly better results. However, they have still come up short when students attempt to understand why a negative times a negative is a positive (one exception is Linchevski & Williams, 1999). The textbook that had been adopted by the teachers' school used neutralization imagery and they noticed that their students had difficulty understanding integer subtraction in more than a procedural way. Therefore, at Stephan's suggestion, they decided to create a new instructional sequence that used linear imagery and would be placed in the context of finance.

### **Theory of design**

The approach that served as the basis for the design of the teacher researchers' final instructional theory is Realistic Mathematics Education (RME). The roots of RME are based on Freudenthal's idea of mathematics as a human activity (Freudenthal, 1973). In order to mathematize, an individual must organize and structure their world mathematically and the role of a designer is to find didactically rich experiences for students to mathematize (Gravemeijer, 1994). In addition, students are encouraged to create and reason with models and mental imagery associated with the physical tools, inscriptions and tasks they employ. The instruction designed in this study attempted to help students mathematize by reasoning within a context for an extended period of time, moving from concrete toward abstract reasoning with meaningful symbols. The transition from concrete to abstract reasoning is supported instructionally by helping students create models of the context and as the taken-as-shared purposes and mathematical practices evolve, the models shift to serve as models for more abstract reasoning.

Once an instructional sequence has been designed, Gravemeijer (1994) suggests that the designers engage in a thought experiment with the sequence to anticipate the trajectory that the class might follow as the teacher implements the sequence. The trajectory has been labeled a *hypothetical learning* trajectory in that designers make conjectures about the mathematical route the class will travel as it engages with the instructional tasks and hypothesize the means by which the class will be supported in progressing along that route. After implementation, the designer analyzes the results of student learning and revises the instructional sequence accordingly. Another classroom experiment occurs with a newly revised, hypothesized learning trajectory and the results feedback to inform future implementations. At the completion of the Design Research Program the designer creates a well-researched, stable local instructional theory for future adaptation by other teachers.

In the case of the integers Design Research Program, the instructional theory that resulted from five cycles of classroom-based experiments is organized in a table that is separated into five categories (Stephan et al., 2003): the tools, imagery, activity/taken-as-shared interests, possible topics of mathematical discourse, and possible gestures and metaphors (Rasmussen, Stephan & Allen, 2004) that would support students' learning of integer operations (see Table 1). The instructional theory has been broken into Six Phases to delineate the proposed shifts in mathematical thinking that the teacher researchers attempted to support in their classrooms. The Six Phases each correspond to conjectured, taken-as-shared activities and purposes that we expected to emerge as students engaged in the problems.



Table 1: The FINAL instructional theory for integer addition and subtraction

Phase	Tool	Imagery	Activity/Taken-as-shared Interests	Possible Topics of Mathematical Discourse	Possible gesturing and metaphors
ONE	Net Worth Statements	Assets and debts are quantities that have opposite effect on net worth	Learning finance terms	<ul style="list-style-type: none"> <li>Conceptualizing an asset as something owned, a debt as something owed</li> <li>Conceptualizing a net worth as an abstract quantity (not tangible)</li> </ul>	
TWO	Net Worth Statements (Vertical number line)	Differences in Collections of assets & Collections of debts	<ul style="list-style-type: none"> <li>Determining a person's net worth</li> <li>Who is worth more?</li> </ul>	Different strategies for finding net worths	Pay off
THREE	Symbols (+ and -)	+ means asset and - means debt	Determining and comparing net worths	<ul style="list-style-type: none"> <li>Different strategies for finding net worths</li> <li>Creating additive inverses as objects</li> </ul>	Pay off
FOUR		Good decisions increase net worth Bad decisions decrease net worth	Which transactions have good and bad effects on net worth	When taking away an asset is this good or bad? When taking away a debt is this good or bad? <ul style="list-style-type: none"> <li>Judging the results of transactions and therefore direction to move on a number line</li> </ul>	Arms moving up and down to indicate good or bad movements
FIVE	Vertical number line (VNL)  <b>Model of to model for transition</b>	Empty number line to express (+ and -) movements	<ul style="list-style-type: none"> <li>Transactions</li> <li>Reasoning with number line to find a net worth after a transaction has occurred</li> </ul>	<ul style="list-style-type: none"> <li>How do various transactions affect net worth</li> <li>Going through zero</li> <li>The affect of different transactions</li> <li>Different strategies for finding net worths</li> </ul>	Arms moving up and down to indicate good or bad movements  Pay off
SIX	Unknown transaction/ Net Worth problems		Determining different possible transactions	Inventing integer rules $+(+) = +$ $-(-) = +$ $+(-) = -$ $-(+ ) = -$	Pay off

In *Phase One* in Table 1, the first tool to be introduced to students is a net worth statement that lists the “assets” and “debts” that a person has. In the United States, *assets* refer to property or other things that are owned and can contribute to paying down one’s *debts* (or money owed). *Net worth* consists of the difference between one’s assets and debts and is sometimes positive or negative. This net worth template builds on students’ imagery of possessing assets and debts, and the effect it has on one’s financial situation. Students might connect net worth, assets, and debts quite readily, especially at a time in which economic hardships abound in their community. Here it is intended that students construct the idea that a net worth is an abstract quantity, not a concrete entity that can be counted like money, but rather the “status” of one’s financial value. While debts and assets has been debated as a possible context for integers (Mukhopadhyay et al., 1990; Schwartz et al. 1993/1994), *net worth* as an object that can be represented on a number line has not. Net worth has a contextual advantage over using assets and debts alone in that not only can net worth be an *object* with positive and negative properties and can be ordered on a number line, but net worth can also be transformed by *actions* (add or subtract) to produce new net worths. These actions and their results can also be inscribed on a vertical number line.

*Phase Two* envisions students using statements about assets and debts to solve problems in which they find and compare net worths to each other. For example, students are given a listing of the assets and debts of two people, and asked to find and compare their net worths. The goal that the teacher/researchers conjecture will become taken-as-shared is to see which person is worth more than the other. The teachers anticipate that students will create different strategies for finding a person’s net worths, such as 1) finding the *total* assets then *total* debts, and the *difference* between them, and 2) adding assets and debts one at a time until finished. They expect discussions about the “fictive” nature of a negative net worth (Glaser, 1981); what it means for a person’s finances to be worth less than zero. Students will wrestle with the idea that most assets are tangible (e.g., motorcycle) but debts are not (e.g., a mortgage). Even a net worth, whether positive or negative, is intangible and represents the *difference* between one’s asset *value* and debt *value*. Students’ reasoning as they compare two net worths provides the opportunity to introduce a vertical, empty number line (VNL)<sup>2</sup>. For example, the teachers pose tasks that require students to place the net worth of Jackson (\$10,000) and Hayden (-\$45,000) on a VNL. They are then asked to find by how much the two net worths differ.

Up to this point, the tasks use the words “asset” and “debt” to represent the positive and negative nature of integers, respectively. *Phase Three* involves vertical mathematization, scaffolding students’ symbolizing from reasoning with unsigned to signed integers. To this end, activities are posed that introduce assets and debts with the + and - signs rather than the words “asset” and “debt.” Teachers can expect students to continue to use their invented strategies for finding and comparing net worths. Some net worth statements are designed intentionally so that a third strategy might emerge, that of cancelling assets and debts that are equal, and working with the remaining assets and debts.

The *Fourth Phase* seeks to confront one of the conceptual stumbling blocks reported in the literature involving students making sense of *why two negatives make a positive*. At this point,

<sup>2</sup> The inspiration for the vertical number line came from previous Design Research with elementary students’ mathematical reasoning with a horizontal number line (Cobb, Gravemeijer, Yackel, McClain, & Whitenack, 1997).

transaction activities are enacted to help students build on their intuitions to construct an imagistic basis for operations. Students are to judge the effect that various transactions will have on a net worth. Teachers can capitalize on students' gesturing as they describe the up and down effects on net worths. These tasks are written to encourage students to create negative and positive signs as both a *process* and *object* where the first sign signifies an action/transformation (Thompson & Dreyfus, 1988) and the second represents the *status* of the quantity (negative/debt or positive/asset). Thus,  $-(-100)$  is read as "taking away a debt of \$100" and  $-(+90)$  as taking away an asset of \$90. Students are asked to judge whether or not the symbols signify what they called a "good decision", one that makes the net worth get better or a "bad decision", one that decreases the net worth.

The *Fifth Phase* incorporates tasks that encourage students to find the effect that various transactions have on a person's net worth. These tasks are called *transaction tasks* because they involve taking a person's original net worth, performing a transaction on it (like adding a debt) and determining his new net worth. While some students might perform erroneous calculations, teachers can expect "going through zero" to arise as an efficient strategy from students as predicted by Peled and his colleagues (Peled, Mukhopadhyay, & Resnick, 1989). For example, if the task is to find out what happens to Chris' net worth (\$1000) if she takes away an asset of \$1500, the teachers can re-introduce the empty number line (VNL) to make students' going through zero strategy more visual for the other students (Chris will have to pay off \$1000 to get to \$0 and she will still be in debt \$500). In this way the VNL re-emerges in the class from student thinking as a *model of* transactions on net worths. Later, it might evolve to become a *model for* the formal integer operations of addition and subtraction (Gravemeijer & Stephan, 2002) in less context-dependent problem situations.

In the *Sixth Phase*, some activities require students to determine the results of various transactions including multiple ones like  $100 - 2(-50)$ . At first the problems are posed in context and move towards number sentences. To formalize the rules for integer operations, students are asked to list various transactions that could have taken place to make Chad's net worth go from \$10,000 to \$12,000. Students will write  $+(+2000)$  as the unknown transaction,  $-(-2000)$  or others like  $-(-1000) - (-1000)$ .

We have just described the instructional theory for addition/subtraction of integers that resulted from five years of Design Research. In the next portion of this chapter, we turn to the Implementation Phase of Design Research to examine the processes by which this final instructional theory was created.

## 5. Five years of implementation

The Implementation Phase has been broken down into different years to show the progress and effect that the implementation and analysis phase each year has on subsequent iterations. We have already described the work that had been conducted in the preliminary design phase of year one (literature review, design first instructional theory and thought experiment). In the next section we describe the first year's implementation and the subsequent analysis that provided feedback to change the learning trajectory. Although design phases were conducted each year, we do not discuss them each year (except Year Three) to save space.

### Year one implementation (Stephan and co-teacher)

As mentioned in an earlier section of this chapter, the Integer Design Research Program was motivated by the pragmatic concern of needing instructional materials that helped students

make sense of integer addition and subtraction. Theoretically, the teacher researchers hoped to build an instructional theory that could be adapted by other teachers at the school or elsewhere. Being their first year teaching together and due to limited resources, Stephan and her co-teacher created instruction that used assets and debts as the context for integers with the intention of piloting the context to determine its viability. They engaged students in conversations about assets and debts to develop meaning for the terms and then introduce problems like  $100 - (+50)$  to mean a \$100 asset take away \$50 worth of assets. They then posed other problems within the same context such as  $50 - (-40)$  and suggested that the second term meant “taking away a debt, which is a good thing.” However, within the first few class periods, the teachers learned why this context needed to be further developed. On the positive side, students could readily interpret the “taking away a debt” situation fairly easily. However, students could not reason through problems like  $-5 - (-10)$  because “you can’t take away a debt of 10 when you only have \$5 of debt.” This problematic, yet reasonable interpretation led the teachers to make the first significant revision to their initial conjectures. They conjectured that it might be more meaningful if the first number signified a *net worth* and the second, with its associated signs, would represent a *transaction* on that net worth. Therefore, they speculated that  $-5 - (-10)$  might be more meaningfully interpreted if it meant, say, Greg’s net worth was  $-\$5$  and he took away a debt of \$10. The reason this might be more meaningful is that students could reasonably argue that, while Greg’s net worth is  $-\$5$ , he could have \$55 worth of debts and only \$50 of assets. If that is the case, then there is a total debt of \$55 from which to take away \$10 of debt. Therefore, it might make sense to students to subtract a debt of \$10 if what they are subtracting it from is a net worth of  $-\$5$  rather than a debt of  $-\$5$ . This *analysis* of student reasoning and interpretation informed the work in the preliminary design stage for Year Two.

### **Year two implementation (three teacher researchers)**

The following year Stephan and her co-teacher were joined by another 7<sup>th</sup> grade teacher who had observed their classroom and wanted to learn how to teach using a more inquiry-oriented approach. They invited him to participate in the Integer Design Research; he agreed and participated fully as both a teacher researcher and practitioner. The role of the lead teacher researcher was to direct the design and implementation of the learning trajectory while the other two teacher researchers focused on implementing the integer sequence and analyzing students’ learning in their own classroom. During team meetings, all teacher researchers provided important, formative feedback from teaching the lessons by presenting student thinking and at times, generating new instructional activities. As a consequence of additional resources (i.e., time, human, new subjects via another teacher), the team began research meetings two weeks prior to implementing the newly revised instructional sequence. At this time, there was no document resembling Table 1 yet available for discussion, however, Stephan had created a more organized set of instructional activities based upon their work from Year One along with a *hypothetical learning trajectory*. Briefly, teachers would present students with a celebrity’s net worth (in our case Oprah Winfrey, an American celebrity) and ask them what constituted this amount. They anticipated students would list things such as cars, planes, businesses, residencies, etc. but would not consider debts to be part of her net worth without teacher prompting. When lists of both assets and debts were on the board, the teachers would name them and give students an empty net worth statement from an actual financial advising firm (see Figure 2).

Net Worth Statement	
Client Name _____	
<b>Cash Assets</b>	<b>Current Value</b>
Cash Bank Accounts	<input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/>
Money Market Accounts	
Other Cash	
<b>Investments</b>	
Bonds	<input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/>
Stocks	
Mutual Funds	
Annuities	
IRA's	
Retirement Plans	
Real Estate	
Other Investments	
<b>Personal Assets</b>	
Household Contents	<input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/>
Primary Residence	
Automobiles	
Other	
<b>Total Assets</b>	<input style="width: 100%; height: 15px;" type="text"/>
<hr/>	
<b>Debts</b>	
Mortgages	<input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/> <input style="width: 100%; height: 15px;" type="text"/>
Personal or Business Loans	
Automobile Loans	
Credit Cards/Charge Accounts	
Other Debts	
<b>Total Debts</b>	<input style="width: 100%; height: 15px;" type="text"/>
<b>Net Worth</b>	<input style="width: 100%; height: 15px;" type="text"/>

Figure 2: An empty net worth statement

The classes would discuss further the meaning of net worth and assets/debts, and the teachers would pose various activities in which students were given two net worth statements and asked to determine who was worth more (see Stephan & Akyuz, 2012 for details). This corresponded with what would eventually become Phases One and Two of the instructional theory outlined in Table 1.

The teachers then engaged their students in what is now called Phase Three of the instructional theory from Table 1 which intended to move students towards more abstract symbols. Teachers' analysis of the next portion of instruction constituted the second major revision of the learning trajectory. The teachers felt students took-it-as-shared that net worth was the combination of assets and debts (positive and negative integers) and could flexibly interpret positive and negative values in relation to each other. The next step was to introduce transacting on net worths (NW), so they posed word problems like, "Demitrius had a net worth of \$250 but he took away an asset worth \$50. What is his new net worth?" Students were posed a variety of these word problems which contained all eight situations listed: positive NW + debt/asset, negative NW + debt/asset, positive NW - debt/asset, and negative NW - debt/asset. Through a series of carefully sequence problems, students began to write their word problems as symbolic expression, like the Demitrius problem:  $250 - (+50) = 200$ . However, at times, many students had difficulty interpreting the result of transactions.

It wasn't always clear to students whether the net worth was going to dip down or go up and what kind of transaction would cause each. Therefore, the team noted that this would need to be addressed in the next iteration of the instructional sequence.

Students were then posed problems that resembled traditional integer number sentences such as  $500 - (-700)$  as well as  $500-700$ . Students had most difficulty interpreting the second type of problem because they could not decide whether the minus sign was a debt or subtraction sign. This added to the teachers' conclusions that they would need to address transactions in more detail next year. In Year Three, the teachers used their analysis of student thinking to redesign the instructional sequence to include transactions tasks outlined in Phase Four of the final instructional theory.

### **Year three implementation (five teacher researchers)**

Year Three marked the most rigorous classroom experiment yet and allows us to describe the three phases of the Design Research cycle in more detail than the other years. Up to this point in our Design Research, very little formal data had been collected to help us analyze students' learning as they participated in the integer sequence. As Cobb (2003) states, analyses of classroom-based instructional implementations ought to fulfill three criteria: Analyses must 1) document collective mathematical learning over the extended period of time it takes to implement the instructional sequence, 2) permit documentation of individual students' learning as they participate in the collective, and 3) feed back to improve the instructional sequence. To these ends, we embarked on our most formal classroom-based experiment in order that we could document both social and individual mathematical learning as well as determine the supports and constraints that led to that learning. We therefore decided to videotape all teaching sessions from one teacher's classroom during the extent of the integer instruction. We chose only one classroom due to lack of resources for collecting formal data. We also audio taped all small group interactions during class sessions.

We expected the video and audio tape of all whole class and small group discussions to provide us the necessary data for analyzing both collective and individual mathematical development. Copies of all student artifacts were collected daily to aid in these analyzes. Pre- and post-interviews were conducted and video-taped to provide further data for analyses of individual students' development. Finally, we audio-taped every team meeting that involved planning and formative analyses in order to document and explain the changes that were made in real time to the instructional sequence. This final documentation helps us fulfill criterion three regarding providing feed back to improve the instructional design.

Analyses by both Stephan and her colleagues of the collective mathematical learning of the classroom community and the planning practices of the team led to major revisions of the instructional sequence: 1) a stronger focus on the meaning of net worth at the beginning of instruction, 2) the introduction of an empty, vertical number line as a model of students' comparisons of net worths, 3) the integration of transactions tasks, and 4) presenting unknown transaction and net worth tasks. In the next sections we examine the Design Research Cycle in detail.

### **Year three preliminary design phase**

Several weeks before the experiment began, Stephan and the doctoral student read additional literature on students' learning of integers and assembled a set of interview questions. Pre-interviews with all 20 students were conducted to confirm the starting point for instruction and to

document student integer knowledge prior to instruction. This data would lend itself to fulfilling Cobb's (2003) criteria that analyses of classroom-based research should document individual students' learning. One week prior to the implementation of the instructional sequence, all team members met to discuss the results of the student interviews and the hypothetical learning trajectory (HLT) in Table 2, particularly the addition of the number line, and the big ideas (possible topics of discourse) that they were attempting to support. All team members had a copy of the HLT as well as the instructional sequence (i.e., tasks) that resulted from informal analysis of last year's work. The team discussed the long term goals of the instruction, and since one of the team members was new, they discussed the rationale for choosing net worth and finance as the realistic context, the reason for supporting students' modeling with a vertical number line, and the role that students' imagery, gestures and discourse could play specific to the integer instruction.

*Table 2: The hypothetical learning trajectory at the BEGINNING of year three*

<b>Tool</b>	<b>Imagery</b>	<b>Activity/Taken-as-shared Interests</b>	<b>Possible Topics of Mathematical Discourse</b>	<b>Possible gesturing</b>
Net Worth Statement Template	Assets and debts are quantities that have opposite effect on net worth		<ul style="list-style-type: none"> <li>Conceptualizing an asset as something owned, a debt as something owed</li> <li>Conceptualizing a net worth as an abstract quantity (not tangible)</li> </ul>	
Net Worth Statements	Differences in Collections of assets & Collections of debts	<ul style="list-style-type: none"> <li>Determining a person's net worth</li> <li>Comparing net worths</li> </ul>	Different strategies for finding net worths	
Symbols (+ and -)	+ means asset and - means debt	<ul style="list-style-type: none"> <li>Determining net worths</li> <li>Transactions</li> </ul>	<ul style="list-style-type: none"> <li>Different strategies for finding net worths</li> <li>Creating additive inverses as objects</li> <li>How do various transactions affect net worth</li> </ul>	Arms moving up and down to indicate positive or negative affects
Net Worth Tracker (vertical number line)	Empty number line to express (+ and -) movements	Reasoning with number line to find a net worth after a transaction has occurred	<ul style="list-style-type: none"> <li>Going through zero</li> <li>The affect of different transactions</li> <li>Different strategies for finding net worths</li> </ul>	Up and down movement with arms
Coffee Spill Net Worth Statements		Determining different possible transactions	Inventing integer rules $+(+) = +$ $-(-) = +$ $+(-) = -$ $-(+ ) = -$	

After discussing the learning trajectory, the teachers collectively *imaged* the first day of class (Schoenfeld, 2000). *Lesson imaging* is a thought experiment in which a teacher(s) creates a mental picture of the actions, discourse, student thinking and tool-use that might occur during the lesson. For example, a portion of a lesson image of the second day might look like:

*First, I will remind students of the context by asking various students to describe the vocabulary terms on our word wall: especially asset, debt, and net worth. I will hand out the Brad and Angelina task and ask students to help Angelina determine each of their net worths. I'll remind students to record evidence on their papers and be prepared to defend their answers. I think students will make some silly calculational mistakes so before we start discussing the answer, I will have students check their calculations with their partners... Since this is the first time students have encountered a situation where the debts outweigh the assets (Brad), I expect to see students struggle with what that means. Some will probably calculate it correctly (-\$90,000) either putting the negative sign or by calling it a debt. Others will put a zero since they might not yet conceive of negative numbers. Still others may put \$90,000 but not know how to talk about the fact that it is "negative"... (so on).*

The teachers talked about their images aloud and discussed the rationale for certain teacher moves. They attempted to write down the reasoning they anticipated from their students and the possible discourse that might support them, including questions, challenges, order of student presentations, tools, gestures and/or imagery that could be emerge. Lesson imaging as a Planning Practice (Akyuz, Stephan, & Dixon, in press) was essential in creating a "shared" image among all teachers about the intent of activities, the conjectured student reasoning, and the resources teachers could draw on to support enacting the HLT as intended. These "shared images" could then be implemented and results could be brought back to meetings each day for analysis and revision to the instructional sequence. This, and all teacher planning meetings, was audio taped to capture our instructional intent and hypothesized image of how the instruction might take place, including changes that were made to the instructional sequence together with the rationale for doing so. Such data would provide information that would feed back to improve the instructional sequence for next year.

### **Year three implementation phase**

The teachers implemented the hypothetical learning trajectory for integers over a period of 6 weeks. They met almost daily to lesson image, analyze how students engaged with the tasks and create revisions that needed to be made immediately (minicycles of design, implementation and analysis of student thinking). All meetings were audio-taped to document improvements to the design that were made in real time. As it happened, they discovered that opportunities to introduce the vertical number line emerged from students much earlier than anticipated in the HLT in Table 2. This opportunity arose for the first time as early as day three when students were trying to justify how a person's net worth was -400 when she had a total of \$8000 of assets and \$8400 in debts. Students argued that this person must use all \$8000 to "pay off" her debts as much as she can and then she would still be in debt \$400. The teachers capitalized on these arguments and recorded them on a vertical number line. They then created new tasks such as, "Paris is worth \$20,000, Nicole is worth -\$22,000; Who is worth more and by how much?" These problems were posed on a vertical number line to support students' invented strategies for finding differences between two integers (for a more thorough analysis see Stephan & Akyuz, 2012).



The second real-time revision to the HLT occurred towards the end of the implementation when students were solving symbolic number sentences with integers. They posed problems that alternated the unknown by sometimes making a) the transaction missing (e.g.,  $1000 - ??? = 2000$ ), b) the original net worth missing (e.g.,  $??? - (+200) = -400$ ), c) the final net worth missing (e.g.,  $-40 - 20 = ???$ ) and d) the transaction *and* the operation missing (e.g.,  $300 \text{ ???} = -600$ ). These were added because the symbolic sentences that took the form of *original net worth +/- transaction = unknown* were too trivial for students and the other types forced students to reason in more sophisticated ways.

### ***Year three analysis phase***

The teachers created formative assessments of student thinking as needed to assess individual students' reasoning and created a summative assessment at the conclusion to attain a unit grade for parents as well as to document the learning of individual students over time. Results from these assessments provided data useful for analyzing individual's mathematical development at various points in time. Additionally, pre- and post-interviews and surveys of all 20 students were conducted and discussed with the team (for sample items see Table 3). Results of the pre- and post-interviews indicated that when students used a vertical number line as a part of their strategy, they solved addition and subtraction problems correctly over 90% of the time. T-tests on pre- and post-integer tests showed an increase in performance on both addition and subtraction tasks at a statistically significant level. A qualitative analysis was also conducted to document the collective integer learning of the 20-student class. These results indicated that the vertical number line, coupled with a finance context provided a didactically-rich foundation for instruction that help students re-invent the meaning for integer addition and subtraction. These analyses, particularly the qualitative one, resulted in the stable instructional theory outlined in Table 1.

*Table 3: Sample activities from pre- and post-Interviews and surveys*

<p><u>Two Sample Items from the Integers Pre- and Post-Survey</u></p> <p>1. Fill in numbers to make this sentence true:</p> <p style="text-align: center;"> </p> <p>2. Fill in numbers to make this sentence true:</p> <p style="text-align: center;"> </p>	
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Table 3: Sample activities from pre- and post-Interviews and surveys (continued)

<p><b>Two Sample Items from the Integers Pre- and Post-Interview</b></p> <ol style="list-style-type: none"><li>The statements are given in the following. Decide whether the statement is true or not. Explain your reasoning.<ol style="list-style-type: none"><li>If you subtract negative integer from the positive integer, the answer is always positive integer.</li><li>If you subtract positive integer from a negative integer, the answer is always negative integer.</li></ol></li><li>Find which statement has greater answer without doing any calculations. Explain your reasoning.<ol style="list-style-type: none"><li><math>+7,650 + ^{-}1000</math> OR <math>+7,650 - ^{-}1000</math></li><li><math>-3,500 + ^{+}250</math> OR <math>+3,500 - ^{-}250</math></li><li><math>-2,500 - 500</math> OR <math>+2,500 + ^{+}500</math></li></ol></li></ol>
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#### Years four and five implementation (scale up)

Years four and five can be characterized as scale up in that the team grew in size to comprise all of the 7<sup>th</sup> grade teachers at the school. Additionally, Stephan traveled to another school to work with teachers who wanted to adapt the instructional theory to their 6<sup>th</sup> grade classrooms. With each implementation, feedback was collected and integrated into the instructional theory, but no major revisions have been made since Year Three; thus, the instructional theory remains relatively stable in the context of the teachers' schools. Efforts have also been made to provide the materials and instructional theory to a few teachers around the country.

#### 6. Assessment of the program of design research

Other than the interviews, surveys, and tests conducted at the micro level of experimentation, more formal assessments can be used to document the yield of Design Research. The purpose of these assessments is to determine the effectiveness, practicality, relevance, and consistency of the instructional theory (Plomp, 2009, p. 26). For the Integer Design Research Program, practicality was established the minute these 7<sup>th</sup>-grade teacher researchers found a need for better instructional materials for teaching integers to their students. To this day, the same teachers use this instructional theory as their curriculum, showing the sustainability and practicality of it. The theory was relevant in that research showed a need to create instruction that could help students learn integer addition and subtraction with meaning. The theory is consistent (i.e., logically designed) in that it was designed using a heuristic-based design theory (Realistic Mathematics Education) to create and revise it. Finally, Stephan and Akyuz (2012) showed the theory's effectiveness in their formal, published research. Their findings suggest that grounding students' integer work in the context of finance, coupled with a vertical number line, has great potential. Their evidence comes from an analysis of the students' mathematical learning in terms of their development of five mathematical practices as well as the results of pre- and post-tests (see Stephan & Akyuz, 2012). The classroom math practices indicate that students can construct conceptual understandings of integers and their operations. While almost all of the studies on integers report that students had difficulty subtracting negative numbers, T-tests run on students' pre- and post-tests indicated 1) instruction helped students significantly improve their test scores for both addition and subtraction and 2) improvement in subtraction surpassed their improvement in addition.

## 7. Yields of the design research and lessons learned

One of the most significant results of this research was an *instructional theory for integer addition and subtraction* (see Table 1) that can guide other teachers' use of the instructional sequence in other situations. Gravemeijer and Van Eerde (2009) state that teachers must take instructional theories and create hypothetical learning routes for their classrooms that are guided by the theory itself. The teachers from this study have been giving professional development using the instructional theory as well as a teacher's guide to teachers in 12 other middle schools. The instructional theory has been adopted as official materials for teachers throughout these schools to use if teachers choose.

A second yield of this Design Research is a team of 7<sup>th</sup> grade teachers who have learned the value of iterative design, implementation, and revision in teaching. Research literature has remained an important artifact for these teachers as they explore teaching new content. Lesson imaging, in which the teacher uses student reasoning to guide their daily instruction and to adjust subsequent lesson enactments, has become a common practice with these teachers. They have formed a community of teacher learners (Stephan, Akyuz, McManus & Smith, 2012) that consistently plans, implements, and analyzes student learning on a daily basis. They look for textbooks and materials that utilize realistic contexts and support students to re-invent mathematics. Finally, these teachers continue to value student interviewing prior to teaching most mathematics units as a way to assess student thinking, not just skills. Thus, certain Design Research practices can be highly valued by classroom teachers and sustained, to some extent, without the presence of a researcher.

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## Improving Instructional Coaching to Support Middle School Teachers in the United States

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# 15. Improving instructional coaching to support middle school teachers in the United States

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## Abstract

*This case presents a study that investigated how professional development for instructional coaches in the United States could be delivered more effectively. Further, it investigated how a coaching model could be optimized to support middle school teachers' ability to implement instructional practices. Through an iterative process of development, the coaching model shifted from one of providing teachers with a pre-determined evidence-based instructional practice to a model of helping teachers to identify an instructional practice they wished to address, and then collaborating with a coach to develop a plan for achieving it. Further, through this process, coaches and researchers collaborated to refine how video recordings could be used to help teachers, as well as coaches, engage in self-reflection. Data showed that coaching supports teachers' ability to implement new instructional practices and it revealed the importance of a respectful and trusting relationship between teachers and coaches. Lastly, this case presents lesson learns and directions for future research.*

## 1. Introduction to the problem

In the past decade, teachers in the United States (U.S.) have been expected to change their instructional practices to meet the requirements of the No Child Left Behind mandate (NCLB, 2002) and more recently the Common Core State Standards (CCSS, 2010). In addition to these mandates, the population of students in the U.S. is becoming increasingly diverse culturally and linguistically (U.S. Department of Education & National Center for Education Statistics, 2007). Further, the percent of school-aged students living in poverty 22% (U.S. Bureau of the Census, 2010) and the percent of school-aged students with disabilities is 13% (U.S. DOE & NCES, 2010). Consequently, teachers would benefit from professional development that helps them to implement evidence-based instructional practices that supports the needs of an increasingly diverse student population.

In recent years, school districts have adopted coaching as one approach to professional development for teachers. Despite the numerous models for coaching (e.g., Allen & LeBlanc, 2004; Costa & Garmston, 2002; Duncan, 2006; West & Staub, 2003), there are relatively few empirical studies that demonstrate benefits for teachers and their students (Kamil, 2006). To address this need, we initially attempted to conduct a quasi-experimental study to determine the effectiveness of the Partnership Approach to Instructional Coaching (henceforth, Instructional Coaching; Knight, 2007). However, as coaches and teachers began implementing the Instructional Coaching model, they were becoming frustrated and stressed. Consequently, we began to question the feasibility of the model despite the fact that it had been successfully implemented in the past. As we reflected on the situation, we recognized that changes were needed to the Instructional Coaching model and design research (van den Akker, Gravemeijer, Mckeeney, & Nieveen, 2006) would allow us to revise the model so that it would be more

realistic to implement. Further, the school district and coaches using the Instructional Coaching model in the quasi-experimental study were eager to help us develop the model.

Despite the challenges they were encountering, they did recognize its potential to support teachers. That is, they were invested in the goal of this study, which was to enhance the delivery of professional development to instructional coaches and to increase teachers' ability to evidence-based instructional practices through coaching. They were also invested the outcome, to produce a more refined and feasible model of Instructional Coaching. Thus, the research questions guiding the present investigation were:

1. How can professional development for instructional coaches be implemented to better prepare coaches to support teachers?
2. How can instructional coaching be optimized so that teachers can implement evidence-based instructional practices?

Our study was conducted in three phases. During the first phase, researchers reviewed the literature of coaching and revised the Instructional Coaching model (Knight, 2007) of coaching. During the second phase, the development phase, the revised coaching model was presented to the coaches. Data were collected to understand how the coaches were implementing the model and how teachers were changing their instructional practices. The development phase also consisted of three iterations. During the final phase, retrospective analysis, all data sources were reviewed to gain a deeper understanding of Instructional Coaching model and the outcomes for coaches and teachers

In this chapter we provide the theoretical and empirical basis for the coaching model and we describe the design principles. We discuss the iterative process of data collection and modifications that occurred in the second phase of the study. We also present the outcomes of the study in relation to the design principles. Finally, we reflect on lessons learned and suggest future research.

## **2. Theoretical and empirical basis for the intervention**

In this section, we briefly present the literature related to adult learning and professional development that guided the initial revision of the coaching model. We also present the design principles and conclude with the steps in the Instructional Coaching model.

### **Adult learning and professional development**

To revise the Instructional Coaching model, we reviewed the literature on the adult learning process and professional development. First, research shows that teachers move through stages of change based on their concerns (e.g., Joyce & Showers, 2002; Prochaska, Norcross, & Diclemente, 1994) and coaches can help teachers with their concerns. Second, research suggests that professional learning is more effective if it respects the autonomy of teachers (Davenport, 2005; Knowles, 1973). Finally, research demonstrates that professional learning is more effective when it occurs in the day-to-day context of teachers' work in the classrooms (Sparks, 1994; Wood & Killon, 1998). Consequently, we identified three practices that are important to coaching: differentiated support for teachers, respect for professional autonomy, and job-embedded professional practice.

### **Design principles**

Five design principles were identified based on that literature review and previous research on the coaching model. First, a structured sequence of activities supports a coach's ability to support teachers.

This structure helps to keep coaches and teachers focused and moving toward the goal of improving a teacher's instructional practice. Second, a partnership or collaborative stance between the coach and teachers supports effective coaching. That is, teachers should be actively involved in the decision making process. Third, a coach should provide differentiated support to teachers to meet their diverse needs. Specifically, coaches need to take into consideration issues such as teachers experience, the content to be taught, and the instructional needs of teachers' students. Fourth, a coach should respect the professional autonomy of teachers. Finally, coaching should be job-embedded; that is, occurring in the context of teachers' work in their classroom.

### The partnership approach to instructional coaching

The Instructional Coaching model under investigation involved a sequence of activities designed to help coaches engage in coherent interactions with teachers (Knight, 2007). Specifically, Instructional Coaching consisted of coaches (a) recruiting teachers, (b) planning coaching sessions, (c) preparing for sessions based on content teachers would be teaching, (d) demonstrating how the content could be taught using an instructional tool, (e) explaining the steps of how the tool could be implemented with students, (f) modeling how to implement the instructional tool in the teacher's class with his/her students, (g) observing the teacher implementing the instructional tool, and (h) exploring how the teacher implemented the tool to identify strengths and weaknesses of implementation.

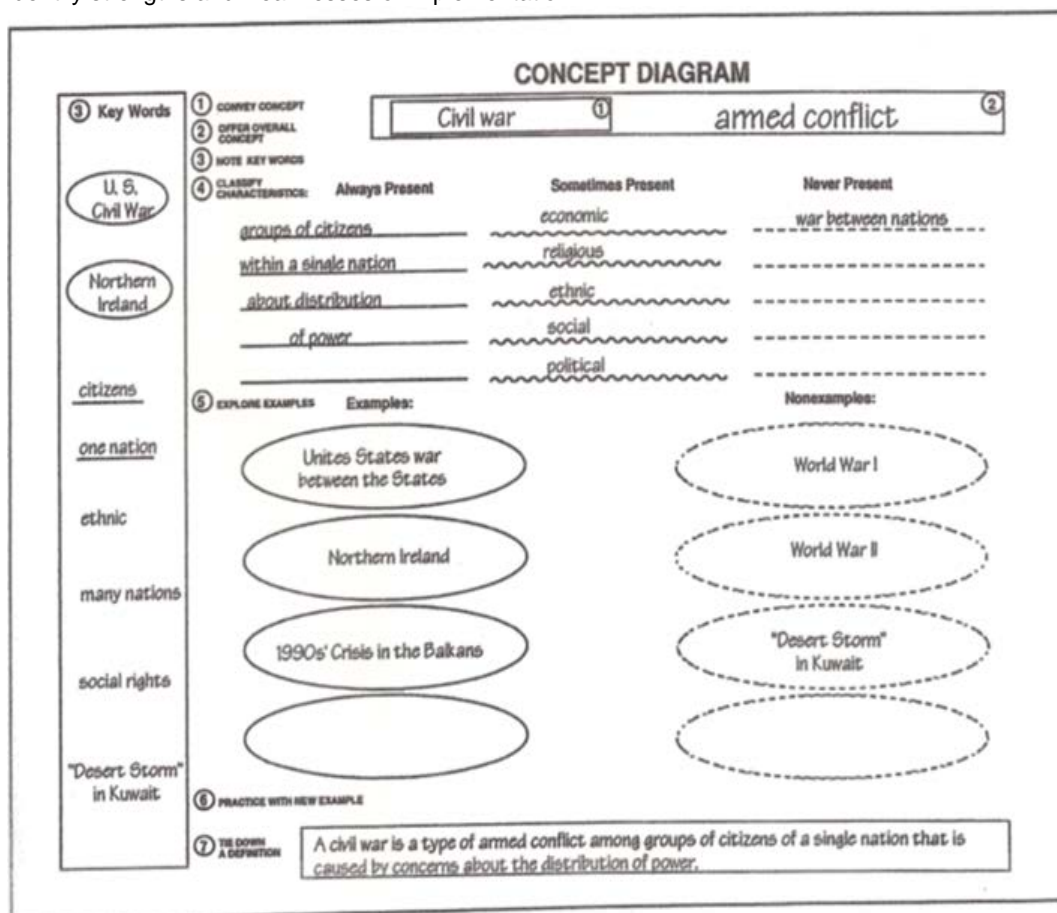


Figure 1: Concept mastery routine

While any evidence-based instructional tool could have been used, we choose Concept Mastery Routine (Bulgren & Scalon, 1997/8; Bulgren, Schumaker, & Deshler, 1988) because coaches were familiar with it and teachers across different content areas (e.g., science, social studies) have found it to be useful. The Concept Mastery Routine (CMR) is a diagram (see Figure 1) that allows a teacher and students to discuss an important concept as they complete the diagram together. Specifically, students develop a better understanding of the concept as they brainstorm characteristics that are always present, sometimes present, or never present in the concept, provide examples and non-examples of the concept, and write a summary statement about the concept.

### **3. The development phase**

In this section we describe the participants, the school setting, and how data were collected and analyzed. We also describe each of the three iterations, the results, the modification made to the coaching model, and new questions or issues that were raised by those results.

#### **Participants and site**

Participants were four instructional coaches and eight middle school teachers working in a small city located in the Northwest region of the U.S. All coaches had been classroom teachers and had from 1 to 6 years of coaching experiences, while teachers ranged from 7 to 16 years of teaching experience. The coaches and six of the teachers are female. Coaches recruited teachers based on their knowledge of the teachers' instructional practices and the teachers' interest in being coached. Teachers included two English/language arts teachers, two social studies teachers, one math teacher, one science teacher, one art teacher, and one teacher of English language learners. Lastly, each coach worked with only two teachers because two coaches were employed part-time, one coach had teaching responsibilities, and last coach had administrative responsibilities with the school district.

In the past 10 years, the school district had an increase in enrollment of minority students from 24% to 43%, an increase in students eligible for free or reduced lunch from 17% to 33%, and an increase in students learning English as a second language from 9% to 15%. The percent of students eligible for special education services remained fairly consistent at 11%. With respect to state assessments, 23% of middle school students did not meet expectations in reading, 19% did not meet expectations in math, 40% did not meet expectations in writing, and 24% did not meet expectations in science. Thus, the school district was interested in helping teachers to improve their instructional practices, as needed, to support student learning.

#### **Data sources and analysis**

Data sources consisted of video recordings and transcripts of (a) the professional development workshops for coaches, (b) coaching sessions, (c) some classroom teaching, (d) semi-structured interviews with coaches, and (e) semi-structured interviews with teachers. Further, data included coaches' journals, documents such as coaching checklists and observations notes of classroom teaching.

Video recordings were transcribed verbatim, then the videos were watched and transcripts were cleaned and edited (Skrtic, 1985). Afterwards, the videos were viewed and transcripts were read several times in order to code and categorize the transcript data. Some categories were based on the coaching process. That is, transcripts were categorized to determine what aspects of the Instructional Coaching model the coaches were implementing, not implementing, or modifying. Other categories emerged as transcripts were read and re-read.

Next, data from categories were reviewed across teacher-coach dyads, discrepancies discussed, and categories refined. Lastly, data were then reviewed once again to identify key themes within categories. Themes also were discussed and refined. However, because of the extensive amount of data collected and the time needed to analyze it, data were fully analyzed for four teacher-coach dyad and decisions to modify professional development and the coaching model were made based those findings. Data from the remaining dyads were analyzed during retrospective analysis. Thus, after data from the four dyads were analyzed, a summary of the findings was shared with coaches during the professional development workshops held after each iteration, and it used as part of the member check process. Modifications for the coaching model were further refined during these workshops based on discussions with the coaches.

### **Iteration 1**

Prior to implementing the Instructional Coaching model, the coaches participated in a 3-day workshop. The purpose of this workshop was to teach coaches about the revised coaching model and how to implement it. Coaches also were given information about their collaborative role in the research process. Following the workshop, each coach recruited two teachers to participate in coaching. This iteration occurred between August and December of Year 1.

### **Results**

Briefly, Instructional Coaching consisted of coaches (a) recruiting teachers, (b) planning sessions (c) preparing sessions based on the teacher's content, (d) demonstrating the CMR using class content, (e) explaining the steps of how to use the CMR with students, (f) modeling how to implement the CMR in teacher's class, (g) observing/video recording the teacher implementing the CMR with his/her students, and (h) exploring the video recorded session with the teacher to identify strengths and weaknesses of implementation.

First, data analysis from Iteration 1 revealed that with the exception of how coaches modeled implementing the CMR in the teacher's class, they were able to implement the other procedure of the coaching model with fidelity.

Coaches provided several reasons why they did not model the CMR. For example, it was challenging to schedule a time that was both appropriate to introduce the CMR to students given where they were in the course content and that fit the coaches' schedule. Also, coaches indicated that some teachers felt comfortable using with CMR with the coach modeling it. Or, teachers preferred that the coach co-teach with them using the CMR, so that they could troubleshoot problems that might arise together. Second, based on interviews, both coaches and teachers indicated that a strong relationship (e.g., trust and respect) is necessary for effective coaching to take place. This was a theme that emerged during the next two iterations. Coaches told us repeatedly that it was important that they maintain a collegial and supportive role towards teachers. On occasions, coaches indicated that they believed administrators wanted feedback on teachers' progress, to use, in part, to evaluate teachers. Coaches strongly maintained that their role was to support teachers and not to evaluate them. Teachers also expressed this concerned but indicated that they believed coaches were truly there to support their practices and not to evaluate them.. Third, based videos and transcripts, when coaches provided direct and specific feedback (e.g., "I noticed 20 students had their hands up during questioning", rather than "You're really an engaging teacher.") teachers were more likely to engage in self-reflective talk. That is, feedback like this helped teachers to talk more specifically about their instructional practices - those that supported or did not seem to support student learning. Fourth, based on observation of videos of teaching and coach interviews, class management was identified as an important precursor for effective practice to take place.

That is, even though teachers were implementing the CMR with fidelity, there were others issues in the class that hindered student learning. Fifth, even though coaches and teachers liked the CMR, coaches believed that they were being too directive and that teachers didn't have enough input into the instructional practice. Lastly, based on interviews, viewing video recordings, though initially uncomfortable, supported the coaching process. However, based on video recordings, we noticed that teachers and coaches often lacked or lost focus when viewing and discussing the videos and that viewing videos was a time consuming process. See Table 1 for more information about the research questions, data collected, examples of findings and modifications as it pertains to Iteration 1.

### ***Modifications***

On these findings, Iteration 2 was guided by three objectives.

The first objective was to use the video recordings more effectively for professional development of coaches and during coaching sessions. The second objective was to increase teachers' engagement in critical self-reflection. To achieve these objectives, during the next professional development workshop, coaches were asked to view, identify, and share two strengths and two weaknesses related to their video-recorded coaching sessions. Coaches found this activity to be particularly helpful to them. It also provided the framework coaches could use to help teachers engage in self-reflection and to identify practices they wished to change. Further, during the workshop, the coaches and research team discussed verbal interactions that supported teachers' self-reflection and developed a list of open-ended comments and questions to facilitate self-reflection (e.g., "What change would you like to see in your students?" "If things were ideal in your class, what would be different? What would you see and hear?"). Lastly, because data revealed that some teachers struggled with class management (e.g., establishing class rules and routines, responding to inappropriate student behaviors) and there was desire to give teachers more autonomy, the coaching model was changed from providing teachers with a pre-determined instructional practice (i.e., CMR), to helping teachers identify an instructional practice that they wished to improve. That is, in Iteration 1 coaches used a "push" model of coaching, but in Iteration 2, they used a "pull" model of coaching (Hargrove, 2008).

Table 1: Research questions, data collected, and some finding and modifications from Iteration 1

Research question	Focus questions Iteration 1	Data collected	Example of findings	Modification based on Iteration 1
How can professional development for instructional coaches be implemented to better prepare coaches to support teachers?	<ul style="list-style-type: none"> <li>• Can coaches implement the coaching model?</li> <li>• What supports do they need to coach more effectively?</li> </ul>	<ul style="list-style-type: none"> <li>• Video recordings and transcripts of the coaching sessions</li> <li>• Interviews with coaches and teachers</li> </ul>	<ul style="list-style-type: none"> <li>• With the exception of modeling, coaches could implement the model with fidelity</li> <li>• Coaches and teachers sometimes lacked/lost focus when viewing the videos effectively with teachers</li> <li>• Coaches need support to help teachers engage in self-reflection</li> </ul>	<ul style="list-style-type: none"> <li>• During professional development, coaches independently viewed videos of their coaching sessions, then shared and discussed strengths and weaknesses. Coaches developed a plan to improve their coaching skills. This approach was then used with teachers.</li> <li>• Coaches and researchers collaborated to develop a list of questions and comments to engage teachers in self-reflection</li> </ul>
How can instructional coaching be optimized so that teachers can implement evidence-based instructional practices?	<ul style="list-style-type: none"> <li>• Can teachers implement the instructional tool? What challenges do teachers encounter and can coaches help teachers to identify those challenges?</li> <li>• What works and what challenges do coaches' encounter when interacting with teachers?</li> <li>• What aspects of the coaching model are helpful to teachers and what kind of support do teachers think they need?</li> </ul>	<ul style="list-style-type: none"> <li>• Video recordings of some classroom teaching</li> <li>• Video recordings and transcripts of the coaching sessions</li> <li>• Interviews with coaches and teacher</li> <li>• Coaches' journals</li> </ul>	<ul style="list-style-type: none"> <li>• Teacher could implement the instructional tool</li> <li>• Coaches concerned that they may be too directive during coaching and not helping teachers to have ownership of the process</li> <li>• Coaches and teachers thought viewing videos of teaching was helpful but time consuming</li> <li>• Teacher found coaching helpful; some teachers requested more support related to formative assessments</li> </ul>	<ul style="list-style-type: none"> <li>• Coaches and researchers collaborated to develop a procedure for teachers and coaches to view videos.</li> <li>• The coaching model was changed from a "push" model where coaches gave an instructional tool to teacher, to a "pull" model where coaches helped teachers to identify an instructional problem and to develop a goal and plan.</li> <li>• Coaches were provided more training and resources related to formative assessment to help teachers.</li> </ul>



## **Iteration 2**

During Iteration 2, the four coaches continued to work with the same two teachers. The revised Instructional Coaching model consisted of coaches (a) viewing videos with a teacher of his/her teaching and identifying an instructional goal, (b) developing a plan to address that goal and determining how to measure progress toward that it, (c) modeling the identified practice in the teacher's class, (d) observing and video recording the teacher, and (e) viewing the video with the teacher and discussing his/her progress toward the goal. This iteration occurred between January and May of Year 1.

## **Results**

There were four primary findings after analyzing the data. First, when the teacher and coach watched the video recording of the teacher's class instruction separately and then met to discuss the videos, the coaching sessions were more productive. That is, both the teacher and coach came prepared with what they thought were key issues. Second, teachers were able to identify their own strengths and weaknesses after viewing the video recording, but they needed guided support to identify a specific instructional goal to address. That is, some teachers had difficulty choosing one issue to address or recognizing that addressing one issue (e.g., setting clear expectations) might help them to address another issues (e.g., behavior management). Third, while the coaches and teachers all agreed that asking teachers identify an instructional goal and then collaboratively develop a plan was a worthwhile endeavor, they all indicated that it was time consuming process. Specifically, coaches told us that it took time to identify a specific goal, to find appropriate strategies and/or to determine a simple means of collecting data to determine progress toward the goal. Lastly, as previously indicated, each coach had identified a coaching practice she wished to change during the professional development workshop, and data indicated that coaches' were engaging in more effective practices (e.g., providing direct and specific feedback, engaging in active listening).

## **Modifications**

On these findings, Iteration 3 was guided by one objective; specifically, to increase the efficiency of identifying an instructional goal, developing a plan to achieve that goal, and identifying a means to gather data that measures progress toward the goal. To address this objective, the Instructional Coaching was again modified so that coaches would help teachers identify an area of need based on the three broad areas of instruction: class management, content planning, and formative assessment of student learning. During their professional development workshop prior to Iteration 3, coaches received training on these three topics. Also, to help teachers to develop an achievable instructional goal, coaches were provided training and guidelines for developing a SMART goal. The SMART acronym for this project was defined as creating a goal that was specific, measurable, attainable, realistic, and timely. Lastly, coaches were given materials that would help them to identify methods for collecting data to determine if progress was made toward a goal.

## **Iteration 3**

During Iteration 3, each of the four coaches continued to work with two teachers. However, in this final iteration, coaches continued working with one teacher from the previous iterations and they recruited one new teacher. This iteration occurred between February and June of Year 2.

## **Results**

Results from this final iteration showed that coaches and teachers were able to identify a goal, a plan, and an assessment to measure progress toward the goal more quickly. Further, teachers indicated that collaborating with a coach to write a SMART goal was helpful and they believed they had “ownership” in the process. Data also reconfirmed many of the findings established from the previous iterations. For example, data revealed that the use of videos continued to be a valuable tool for helping both coaches and teachers identify strengths and weaknesses. Also, direct and specific feedback continued to help teachers to engage in self-reflection and to make changes to their instructional practices. Finally, teachers and coaches continued to indicate that a strong relationship was important to their collaboration and success.

## **Retrospective Analysis**

At the conclusion of the Iteration 3, we conducted a retrospective analysis (Cobb, McClain, & Gravemeijer 2003) based on all teacher-coach dyads. This included the video of each coaching session, the coaches modeling the instructional practice, and the professional development workshops for the coaches. This helped to ensure a thorough and rigorous analysis of data that results in empirically based instructional recommendations (Cobb, Confrey, DdiSessa, Lehrer, & Schauble, 2003). In the following section we present conclusions based on the retrospective analysis.

## **4. Conclusions**

Four key findings emerged from the data and shaped how the Instructional Coaching model will be implemented in the future. First, we present how the Instructional Coaching model changed from push coaching to pull coaching and, second, how we broaden our conceptualization of coaches modeling for teachers. Next, we discuss the role of self-reflection and how video recordings can be used to support it. Lastly, we discuss the importance of a trusting and respectful relationship between the coach and teacher. Further, we address these themes as they pertain to the design principles (i.e., structured sequence of coaching activities, partnership between the coach and teachers, differentiated support, professional autonomy, job-embedded coaching) that guided the coaching model.

### **Partnership approach to instructional coaching**

Two primary issues emerged related to Instructional Coaching model: “push” versus “pull” coaching and coaches modeling instructional practices for teachers. First, push coaching involves the coach presenting a pre-determined instructional tool to teachers and helping them implement it with fidelity, while pull coaching involves a coach helping teachers to identify their own instructional needs and then identifying an instructional practice to address that need. Based on the interviews, teachers and coaches did find value with the CMR presented in Iteration 1, and teachers discussed plans to continue using the tool. Despite this, coaches were concerned about long-term teacher “buy in” because, in part, coaches believe they were being too directive and doing most of the talking during coaching sessions. That is, coaches believed that push coaching did not allow them to fully enact several design principles. Specifically, developing a partnership with teachers, differentiating support, and allowing teachers professional autonomy. Based on videos of push coaching, coaches did do most of the talking. However, during videos of pulling coaching, teachers did talk more during those sessions, and they demonstrated greater enthusiasm about the goal. Further, teachers indicated they appreciated the pull model because of their “control” and “ownership” in identifying a weakness and that they felt more invested when developing a plan of instruction. Lastly, the boundaries (e.g., identifying a need related to class management, content planning, or formative

assessment student learning) and structure (e.g., developing a SMART goal) introduced to the model in the third iteration, resulted in a more expedient process.

Second, modeling or demonstrating how to implement an instruction practice with students is an important component of coaching (Kretlow & Bartholomew, 2010), and both coaches and teachers talked about its value. Yet several factors prevented coaches from modeling instructional practices in teachers' classroom. For example, it was difficult for the coaches and teachers to find a time that fit both their schedules for the coach to model or demonstrate the instructional practice with a teacher's class. Further, coaches indicated that at times, modeling certain instructional practice seemed illogical. That is, coaches did not think that they should model practices such as setting class expectations and "wait time," or that they could model practices such as managing behavior because students behaved differently with them as compared to the teacher. Based on observations of the coaching sessions and interviews, the five modeling routines were identified. They include a coach demonstrating the instructional practice (a) by thinking aloud how she would present the strategy to students, (b) in the targeted class, and (c) in a non-targeted class. The fourth approach was that the coach and teacher would co-teach the instructional practice and, finally, the teacher might observe another teacher implementing the instructional practice. In sum, modeling or demonstrating the instructional practice is an important component to coaching but there are several alternative methods that may be equally effective for helping teachers to understand how to implement the instructional practices. Thus, regarding the design principle related to a sequence of coaching activities, we recognized that least modeling needed to be conceptualized more broadly to address contextual constraints such as scheduling and the nature of the instructional activity.

### **Self-reflection**

Self-reflection is important for effective teaching (Schön, 1987) and, not surprisingly, when coaches and teachers engaged in self-reflective talk they were more likely to change their coaching and instructional practices, respectively. To further support self-reflection by coaches and teachers, two elements of coaching model were modified.

First, videos were a powerful tool supporting self-reflection because it allowed coaches and teachers to discuss events they could view together, rather than to rely retrospectively on what they remembered or thought happened. Further, they indicated that this allowed them to discuss events objectively and reduced the feeling of being evaluated because they could easily rewind the videos and review event in which they interpreted differently. However, just watching a video was not enough. Guided viewing was necessary for teachers and coaches to engage in critical self-reflection. Specifically, coaches and teachers were asked to view videos and identify two clips in which they were pleased with their actions and two clips that they believed their actions could or should be changed. This minor change provided the focus that coaches and teachers needed to engage in self-reflective talk. Further, a set of open-ended questions developed by the coaches and researchers also supported purposeful and collaborative viewing of videos. For example, questions such as "This is what I wrote down, how do you see it?" or "Did I get this right, or did I miss something?" helped teachers and it created a more open and positive environment. Overall, coaches deemed effective questioning strategies as another critical aspect of coaching. Finally, both modifications better support the design principles of developing a partnership, differentiated support through self-reflection, and respecting professional autonomy.

## **Relationships**

When coaches and teachers were asked about what components of coaching were essential, they all indicated that a trusting and respectful relationship is critical for effective coaching to take place. Because coaches and teachers knew each other well and/or had previously worked with each other in some capacity, they may already have had a good relationship prior to the present study. However, based on teacher interviews, recommendations from other teachers appears to influence as to whether or not a teacher will work with a coach. In fact, during the Iteration 3, one of the new teachers reported that based upon the advice of fellow teachers, who were familiar with the coach, she decided to accept the coach's offer of coaching despite not having a previous relationship with that coach. Lastly, the design principle of developing a partnership between coaches and teachers, as well as respecting teachers' professional autonomy, may have helped teachers and coaches to develop a trusting and respectful relationship.

Trust and respect is important to coaching but is it also important to have a relationship based similar discipline knowledge? That is, is it essential for coaches to have knowledge or expertise in the discipline in which they are helping a teacher to make instructional change? Although not discussed earlier in this case, this is a question we raised with teachers and coaches. Based on interviews, coaches indicated that when they had taught the content, they believed that, at times, they were dominating the conversation. However, when coaches were less familiar with a teacher's disciplinary content, coaches believed they asked "real" questions that helped teachers to clarify their thought processes and stimulated critical dialogue. While teachers indicated that it would be helpful to work with a coach who had taught in their discipline, they also reported that coaches' limited content knowledge didn't hinder coaching. For example, when it came to helping teachers with issues such as behavior management or working with struggling students, coaches often provided useful strategies, tools, and ideas to assist them, and content knowledge wasn't necessary. Further, all coaches reported that they would not hesitate to bring a content expert in to help if it was necessary to the coaching process. Ultimately, both coaches and teachers said that trust and respect was more important than content knowledge. Thus, this finding further supports the design principle of developing a partnership and respecting teachers' professional autonomy.

## **5. Lessons learned**

Although the Instructional Coaching model under investigation was a well-established model that we had used in the past, we remained open to the possibilities of change. This allowed us to move from the push approach to the pull approach to coaching, which allowed teachers to identify their own instructional goal. Also, by recognizing the contextual constraints with in the education environment, we re-conceptualized of how modeling of instructional practices to teachers might be implemented. Lastly, videos proved to be invaluable for helping coaches and teachers to engage in critical self-reflection and for allowing them to improve their practices. However, simply viewing a video was not enough and we now have in place a procedure that allows for focused and guided viewing. In short, we learned that even a well-establish program could be improved.

From a research standpoint, a major lesson learned was how to manage the massive amount of data obtained from the video-recordings and subsequent transcripts. One of the most challenging obstacles was the time needed to transcribe the recordings, clean and edit the transcriptions, and then systematically analyze the data within and across each coach-teacher dyad. In short, the time it would have taken to transcribe and analyze all the data from iteration

would not have allowed us the time needed to make modifications to the intervention based on those findings. Consequently, we made modifications based on each coach's interaction with one teacher rather than with both teachers they worked with during iteration. How to reasonably resolve the problem created by a large amount of qualitative data is an issue we are still contending with. While hiring additional staff to transcribe the video recordings may be one solution, this requires added expense and training. Working with fewer participants is another option, but that reduces the variability and richness that is so important when designing an intervention. Thus, we recognize that we need to more carefully consider the data to be collected and how it addresses the research questions.

### **Future research**

Although we learned much about the instructional coaching model and how to make it more effective for coaches and teachers, several questions were raised that we would like to explore. First, with respect to the pull model of coaching, providing teachers with the opportunity to identify their own instructional goal and to help in the planning process to achieve that goal is important. Teachers had immediate buy-in and were eager to try the new instructional practice. Also, because the goal was focused and measurable, the teachers saw evidence of progress fairly quickly, which further motivated them to address other class issues. For example, one teacher was concerned by her students lack of engagement, so she developed a plan to provide more explicit instructional about class expectations, to provide more attention and praise to students who were on task and she learned to ignore inappropriate behavior. Based on class observations by the coach, as well as video data, the teacher did change her behavior and almost all students were observed to be on task and engage with the first few minutes of class. However, the question that still remains - is there value in the push model of coaching? As discussed in one workshop with coaches, the push model may be helpful when first working with a teacher to help establish a relationship. Although rather than presenting one strategy, as in our first iteration, it might be better to present several evidence-based instructional practices from which the teacher may choose.

This leads to a second question, how does a coach develop a collaborative working-relationship or partnership with a teacher? Because our coaches' primarily recruited teachers they knew, relationships were already established.

Although Instructional Coaching is based on the premise that teachers volunteer to be coached, we know that this isn't true of all situations. For example, in some instances administrators request that a teacher receive coaching. Consequently, understanding how and effective teacher-coach relationships develops is important. To achieve a trusting relationship, all our coaches strongly stated that they, or any coach, must not be involved in teacher evaluation. Once a coach is expected to take on that role, all coaches agreed that teachers would become more cautious, take fewer risks, and, in some instance, lose trust in the coach.

The literature states that teachers must have strong content knowledge to be effective teachers (International Reading Association, 2006), but what role does content knowledge play in coaching? Thus, a third area of future research might address the following question: For coaches to be effective, how much content knowledge must coaches possess to support teachers in a particular discipline? That is, both teachers and coaches indicated that a trusting relationship was more important than content knowledge.

However, teachers did appreciate when coaches knew the content because it was easier for them to "talk the talk" and they could discuss concepts related to content in greater detail.

Coaches also recognized that they could provide insight and clarification about concepts when they knew the content; however, coaches worried that they were “taking over” coaching sessions when they had previously taught the content. In short, further research related to the role content knowledge plays in coaching.

Lastly, videos were an effective tool for both enhancing coaching and professional development of coaches. Using mini-camcorders are convenient because they are compact, easy to use, and videos can be downloaded quickly for immediate viewing. Asking teachers and coaches to identify strengths and weaknesses in their teaching or coaching provided the guidance needed to make the video both effective and manageable with respect to time. Nonetheless, more could be learned about the role video might play in coaching and professional development. For example, participants quickly grew accustomed to being videotaped, but it took longer to get used to seeing themselves on the videos. The emotional complexity of watching yourself on video and its discomfort may be important as real growth might involve some level of discomfort. On the other hand, the use of video reduced the feelings of being evaluated and helped both teachers and coaches focus on instructional practices, student participation, and learning. Also, based on the data collected, it appeared that teachers, and to some extent coaches, viewed the video less frequently over time. This may have occurred because viewing videos is still a time consuming process, even with guidance. However, because it is relatively easy to record, share, and archive recordings, it may be valuable to view several short clips collected over a period of time to look for patterns in instruction and student behavior and/or to determine how well a new instructional practice is sustained. Or, it might be beneficial to watch the same lesson multiple times. In short, further research is needed to understand how videos might be used to support more effectively to support teaching and learning.

Like teaching, coaching is a complex and dynamic process that takes hard work and is sometimes uncomfortable, but with self-reflection and persistence it is rewarding and important for improving teachers’ instructional practices and students’ learning opportunities in schools.

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## Educational Design Using Participatory Action Research – Theoretical Foundations and Applications in a Cross-disciplinary Project on Teaching Climate Change

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# 16. Educational design using participatory action research: Theoretical foundations and applications in a cross-disciplinary project on teaching climate change

Ingo Eilks & Timo Feierabend

## Abstract

*This paper considers the application of Participatory Action Research (PAR) as an educational design research strategy. The theoretical foundations of PAR, which can be described as a collaborative and cyclical strategy that among others can be used for curriculum design in domain-specific educational settings, will be outlined. As an illustrative case, a three-year multidisciplinary educational design research project will be discussed, which focuses teaching the topic of climate change. The potential benefits will be reflected upon with regard to more than a decade of previous PAR usage in curriculum design for science education. These include how PAR creates feasible, research-based curriculum materials, how it contributes to innovative structures in teaching practice, and how it supports continuous professional development among the participating teachers.*

## 1. Educational research, curriculum design, and teaching practice

In 2002, Eilks and Ralle suggested differentiating between two of the central fields of domain-specific educational research - *the empirical analysis of learning processes* and *curriculum development*. In their view, it makes sense to understand these areas as *pure* and *applied research* in domain-specific education, respectively. Although both fields are (or should be) related to one another, and in some cases overlap, they can be divided based on the actions of most of their members. *Pure research* has the primary objective of obtaining empirically based insights into the processes and obstacles of learning science. It mainly applies traditional empirical methods taken from the educational sciences, thereby choosing a quantitative or qualitative method to suit the problem at hand. The research paradigm behind such work is quite often positivistic. In comparison, *applied research* has the primary objective of inspiring changes in actual teaching practices through a variety of activities, including the development of new curricula and innovative teaching materials. The research paradigm behind applied research often remains unclear. Sometimes it orients itself along a specific reference discipline, e.g., applying quality criteria from science in focusing the reproducibility of school-type demonstration experiments in science education.

In the case of chemistry education, De Jong (2000) described the oft-missing interaction between the two fields discussed above to be one of the main system failures in domain specific educational research. In the past, one persistent problem was the parallel existence of two more-or-less independent communities within domain-specific education.

Empirical researchers frequently didn't worry about the particular needs of curriculum developers, nor did they communicate their latest research findings to the teachers in user-friendly form. Curriculum developers often neglected to take relevant research evidence on teaching and learning thoroughly into consideration.

They also largely ignored questions about the effects and/or sustainable implementation of newly-altered curricula and pedagogies (e.g., de Jong, 2000; Costa, Marquez, & Kempa, 2000; Taber, 2001; Van Driel, Beijaard, & Verloop, 2001; Eilks & Ralle, 2002).

All this aside, however, there remains at least one more party of primary importance in the educational arena: *the practitioners*. Teachers in many countries are rarely educated in the methodology necessary to perform either pure or applied educational research. Their interest is neither the search for new general empirical evidence about learning and instruction, nor the development of curricula of general interest. Teachers' primary interest is to efficiently cope with the stresses of everyday teaching and teaching practices in a pragmatic fashion. Huberman (1993) described this '*two communities problem*' between practitioners and researchers as a difference arising from separate norms, rewards and working arrangements. Wilson and Berne (1999) argue that this two communities problem is not specifically related to science education. It also exists in many other educational domains.

Taking into account that teachers are the key to any successful innovations in teaching practice (see Anderson & Helms, 2001), Huberman (1993) suggested that the only way to bridge the existing gap between empirical research and classroom teaching is through sustained interactivity. The same holds true for pure researchers and the curriculum designers. Huberman states that it is necessary to have '*multiple exchanges between researchers and potential "users" of that research*' (Huberman, 1993, p.4). He suggests looking for convergences between the scope of the research and the priorities and interests of the target audience. This includes recruiting key actors in the target group to accompany the ensuing research and help to carry it out. Such help can be seen, for example, whenever practitioners participate in the review and analysis of intermediate findings or identify the data sets of greatest potential use to the target group. Such interaction between researchers, curriculum designers and experienced practitioners recognizes that both empirically-validated research results and experientially-based teacher knowledge represent the two ends of the spectrum of knowledge about teaching and learning. Both areas are equally important and have their own strengths (McIntyre, 2005). Nevertheless, Huberman's understanding of *sustained interactivity* also includes the cooperative planning of how to disseminate any valuable results to the target audience and transform such findings into teaching practices. Huberman recognizes that any sustainable innovation in practice can only be successful if the practitioners' beliefs, their foreknowledge and attitudes are incorporated into the reform and are taken into account seriously (Haney, Czerniak, & Lumpe, 1996; Nespor, 1987). Such innovation must also be carried out step-by-step through experience-based learning practices and self-reflection exercises among the practitioners (Huberman, 1993).

Beginning with the chain of arguments given above, we started our search for a collaborative model of domain-specific educational research about fifteen years ago. The resulting model needed to include the participation of both researchers and practitioners and fulfill three main intentions: 1) designing and developing new curricula with documentation of good practices, 2) innovating authentic practices under the inclusion of continuous professional development among the practitioners, and 3) searching for empirical evidence about the processes of learning and instruction.

The idea of combining educational research and curriculum design with direct practice improvement and professional development put us into uncharted waters. Although there are earlier works available (e.g. Plomp & Nieveen, 2009), to us this was new field and very rare experience was available in the context of combined research and development in the field of

chemistry education in Germany. After analyzing different potential strategies, we decided to develop a suitable application based on the concept of Participatory Action Research (Eilks & Ralle, 2002).

## **2. Participatory Action Research (PAR) for domain-specific education**

There is wide range of models which integrate empirical research, curriculum design, and teaching practice in the educational field, thus making collaboration between researchers and practitioners the core of such research. Each model uses different methodologies and contains differing focal points. Among these different approaches, a large range of different collaboration models was derived from Action Research (AR) (Bencze & Hodson, 1999; Feldman, 1996; Parke & Coble, 1997; Mamlok-Naaman & Eilks, 2012). AR directly steers the research process towards reducing any deficits in social practices. This includes the professional development of the practitioners in the target field. AR always requires practitioners to be active participants in the research and development process. Differences in the interpretations of AR mainly center around the distribution of power, responsibility and control during the research process. The balance of power can either lean more heavily towards the researchers or towards the practitioners, depending on the model selected (Eilks & Ralle, 2002; Mamlok-Naaman & Eilks, 2012).

Within the AR-based model we chose for applied research within domain-specific education, the main objectives are the development, documentation and implementation of new or improved curricula and teaching materials. Our goal is to develop strategies and materials that can potentially help in reducing deficits, while improving teaching practice in as many learning groups as possible. For this reason, we did not take AR approaches which are too practitioner-centered into consideration, since they would be inappropriate for most applied domain-specific educational research. We considered approaches that focus on obtaining more generalized results to be more appropriate for our situation than similar approaches which strive primarily to solve problems within individual groups.

One interpretation of *Participatory Action Research (PAR)* as described in the field of economics by Whyte, Greenwood and Lazes (1989) seemed to us to be the most appropriate model to adapt to domain-specific education. The objective of this research model is to derive results that are widely applicable and based on empirical observations of authentic practices. Even so, the method also aims at improving the actions of the practitioners involved. For the educational field, this means both developing curricula for real-life situations in individual learning groups and appropriately training of the teachers involved as part of the research process. The overall objectives as stated in the centre of figure 1 are equally weight the research interests of developing new concepts and enrich research based knowledge in teaching practice, but in the means of Action Research also improve quality in authentic practice due to research activities. In more detail, we defined the following as objectives of the research process (see figure 1):

- The development of teaching strategies and materials that can improve teaching and learning practices, and the evaluation and dissemination of said strategies.
- The gathering of authentic empirical evidence about the applied learning and teaching practices.
- The reduction of deficits in concrete teaching practices involved in the process.
- In-service teacher training of the practitioners involved pertaining to their awareness of how well they work and the improvement of their skills in curriculum development and evaluation.
- Documentation of the settings and experiences as examples of good practice.



Most interpretations of AR are generally described as a cooperative process between in-service practitioners and external individuals (Mamlok-Naaman & Eilks, 2012). In our case these are practicing teachers in the classroom and science educators from the university. As a matter of principle, the persons involved should be considered having an equally important status and the same right to contribute any decision of the research and development process. They all contribute to each of the decisions made during the research and development process. The objective is to reach a consensus within the group and to agree upon a common strategy. In the end, however, any final decisions concerning changes in concrete practice are left up to the individual teachers. Although both groups are of equal status, it is helpful to think of them as playing different roles (Altrichter & Gsetzner, 1993). The science educators as external researchers focus on organizing and coordinating the research process and evaluating its effects. The teachers concentrate their efforts on developing new curricular approaches in cooperation with the accompanying science educator, translating them into actual practice and testing them thoroughly.

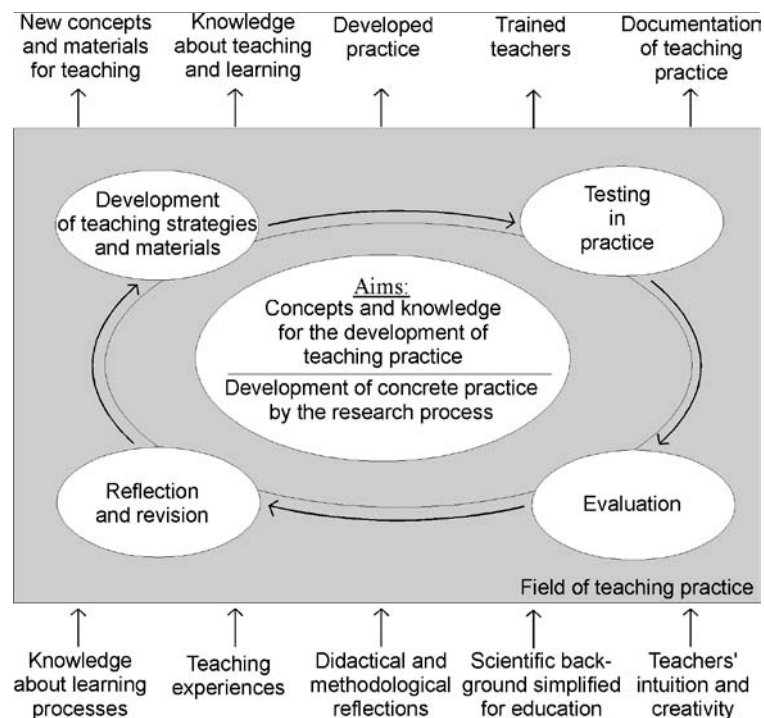


Figure 1: Participatory action research in its operation to science education by Eilks and Ralle (2002)

The research process is initiated when deficits are reported either in concrete teaching practices or in empirical research. The resulting research process is intended to find methods to eliminate or reduce any deficits in these areas through the design and implementation of improved teaching practices. The first step takes the form of group discussions between university researchers and in-service teachers, based on an analysis of relevant literature.

These discussions are used to determine whether or not the problem is of general interest if it stems from individual classrooms. In the case of empirical research deficits, the discussions try to determine whether a reported problem is both authentic and specifically relevant to the field of practice in which the in-service practitioners work.

The group discussions are also used to reflect upon whether any available evidence or suggestions from the review of the literature appears to be feasible for improving a specific educational setting.

Every type of AR is described as being cyclical. This is one of the main differences between AR and other, more conventional research designs (Wadsworth, 1998). At the start of the process, new teaching approaches are designed. They are then implemented, evaluated, and further revised with the objective of improving practices in the testing groups in a step-by-step manner. Information from the domain-specific scientific background, personal experiences reported by the practitioners and participants' intuition and creativity are all used as resources and are made explicit within the group discussion format. This aids in structuring, improving, testing and evaluating the practices developed for the classroom. The initial designs are implemented and tested as early as possible in order to see whether they have the potential to solve the documented problem in teaching practice. The external researchers and active teachers plan the implementation of the curricula together. The group planning process is important, because it ensures that the designs incorporate both the research background of the question and the pragmatic needs of everyday practitioners.

Viewing AR through the lens of critical theory (Moser, 1975; Masters, 1995), the central objective of any AR project is improving practice step-by-step within repeating cycles of development. The direction of change is negotiated within the research group and differs with respect to the intended innovation. E.g. in a project on cooperative learning (Eilks, Markic, & Witteck, 2010) aimed quality was defined with respect to getting more autonomy in learning, raising the level of inquiry during practical work, but nevertheless to get at least the same cognitive achievement with respect to predefined exams. In order to achieve this, each testing cycle must be analyzed and evaluated individually. In our model, the evaluation must take the perspectives of all participants (teachers, students, and researchers) into consideration. The curricula are developed within a practice setting, using close cycles of development and testing. For this reason, evaluation tools and strategies should be chosen that are appropriate for the setting. They can be adapted during the research process as needed, and they should be further refined during each cycle of development. Several methods are suitable, e.g. standardized questionnaires, documentation of verbal feedback, group discussions among the practitioners, or sample interviews with the students. Nevertheless, it has been suggested by Bodner, Maclsaac and White (1999) that strategies applying only traditional quantitative understandings of evaluation are inappropriate for this kind of design research. There are far too many influencing factors and the researchers and practitioners are personally involved. A qualitative and interpretative paradigm is more suitable for this type of research. In our model, the quality criteria for qualitative and interpretative research defined by Altheide and Johnson (1994) are used as a guideline: plausibility, credibility, relevance and importance. Within the evaluation, the practical experience of the teachers, and their assessment of their teaching success, plays an important role in evaluating the research. This is in direct opposition to many classical approaches. Altheide and Johnson's criteria can be tested and/or confirmed during discussions between researchers and practitioners and within the practitioners' group. Documentation of this process is very important to inform practice outside of the research team. This documentation may also include a description of the background and individual interests of the practitioners and researchers (Dickson & Green, 2001). In the end, a reader outside the research group must decide whether he or she feels that the approaches described are authentic, relevant, credible and important, including whether or not they might be beneficial for their personal teaching practices (Mayring, 1999).

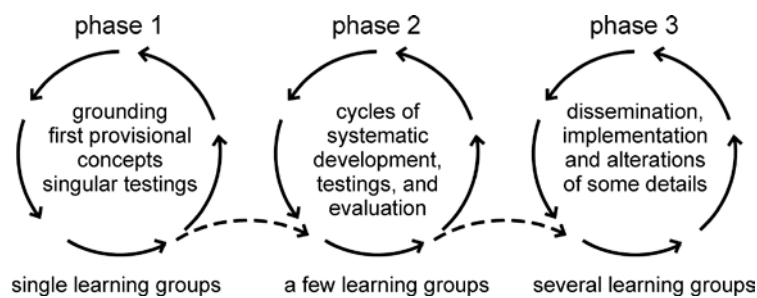


Figure 2: The three phases of PAR in science education. The three phase represent a scaling-up model within the process of research and development. Each phase is made up of one or more cycles as suggested in figure 1. The number of cycles in each phase depends on the consideration of the PAR group whether the experiences and evaluation results suggest that the objectives in each of the phases were achieved.

Based on our experience, it is helpful to define three phases of development that are similar to those described by Stang (1982). Each of these three phases can consist of several cycles of development, testing, evaluation and reflection (see figure 2). The first phase is carried out in a small team of teachers accompanied by the university science educator. In this phase, the problem is considered, the relevant background knowledge is analyzed, and initial, provisional concepts are developed. These concepts are then tested in single learning groups in order to decide whether the planned interventions have the potential to improve practice. With respect this groups can be formed by small learning groups with in a class or single classes as a whole. In the second phase, a team is selected that consists of a group of teachers. The integration of teachers who were not personally involved in the teaching within the first phase is very important. Their inclusion provides impartial feedback on the results of phase one. While the teachers explain and report upon their experiences within the new approach, each group member is forced to rethink any assumptions that he or she initially had. In the second phase, most of the work entails planning changes, carrying them out and reflecting on the results. In the third phase, the main task is the dissemination of the results into practice of classes and schools beyond the PAR group's developmental activity. An additional requirement in phase three is to evaluate whether or not the new teaching methods and materials have been documented well enough so that external practitioners can apply them without additional training. This step is essential that the approaches and materials after publication can be applied by teachers who were not part of the developmental process.

### 3. The case of an interdisciplinary project of curriculum development on teaching climate change in German secondary science and politics education

#### Background of the project

Climate change has become one of the most dominant science-related issues in today's political debate (Ekborg & Areskoug, 2006). Although there is a huge body of literature published about the alleged causes and potential effects of climate change (e.g. IPCC, 2007), there is still no consensus about the implications obtainable from the available data.

This means we are faced with conflicting evidence and quite often contradictory opinions (Hulme, 2009).

Nevertheless, decisions must be reached on both the individual as well as the political levels (Ekborg & Areskoug, 2006). However, the basis for many of these decisions is still undetermined. This makes climate change an interesting topic for contemporary education in general, and for science education in particular (Höttecke et al., 2010). Or in the words of Sadler (2004): The most fruitful settings for science education are “*those which encourage personal connections between students and the issues discussed, explicitly address the value of justifying claims and expose the importance of attending to contradictory opinions*” (p. 523).

Unfortunately, climate change education is not at all as successful as it should be (Rickinson, 2001). Deficits have been reported in several areas, e.g. students’ understanding of the science of climate change and its possible impacts on society (e.g. Andersson & Wallin, 2000; Boyes & Stanisstreet, 1993; 1997; Boyes, Skamp, & Stanisstreet, 2009; Hansen, 2010). But this is not the full extent of the factors which remain lacking. In very few lesson examples within science education literature is climate change connected to the learning of the societal and political dimension of the issue. The societal orientation of science education as a whole remains a neglected field far too often (Hofstein, Eilks, & Bybee, 2011). There seems to be a lack of proper strategies, materials, and their application. A recent survey of twenty German chemistry teachers’ views on and experiences with teaching climate change made it clear that a reliable consensus among teachers as to when, how, and even in which school subject climate change should be taught is still lacking, at least in the case of German schools. Although all of the teachers asked supported the importance of learning about climate change, they themselves did not consider climate change an equally important issue for their curricula as compared to more traditional topics of chemistry education. They also lacked knowledge about suitable pedagogies for teaching the subject (Feierabend, Jokmin, & Eilks, 2011).

### **Objectives and method**

Based on these points, the project ‘Climate Change Before the Court’ was established. The project represented an interdisciplinary cooperation among educators and practitioners in the fields of chemistry, biology, physics, and politics education (Eilks et al., 2011a; Höttecke et al., 2010). Aside from the university and roughly twenty different schools who volunteered to be part of the project, some ten additional partners came from the informal sector of science education, e.g. a science center dealing with the issue of climate, a museum of regional natural history, and regional centers for informal environmental education. The project lasted a total of three years (2008-2011) and was funded by the German Environmental Foundation (DBU). In 2009 it was recognized as an official project of the UN World Decade of Education for Sustainable Development.

Objectives of the project included:

- The development of lesson plans for teaching climate change in lower and upper secondary science and politics education with a special focus on strengthening students’ communication, evaluation and decision-making capabilities under inclusion of a societal perspective.
- Implementing the lesson plans into practice, researching their feasibility and effects, and helping teachers in their professional development concerning the application of the respective teaching strategies.
- Conducting accompanying research on how to deal with the challenge of climate change in domain-specific cultures among educators working in the different science teaching domains.

Designing the lesson plans for each subject (namely biology, chemistry, physics, and politics education) was inspired by the socio-critical and problem-oriented approach to science teaching as originally developed by Marks and Eilks (2009). This pattern for societal and multidimensional-oriented science education organizes lessons using a five-step model (figure 3). The lessons start with a current, controversial socio-scientific issue which is presented to the students using up-to-date, authentic media (e.g. advertisings, newspaper articles, or spots from TV). From the authentic materials the students derive questions about the socio-scientific issue. Some questions always concern the science and technology background, others always strive question from economy, ethics or society. The lessons continue in a second phase of learning, which addresses the essential scientific background necessary for understanding at least the basics of the relevant socio-scientific issue. In step three, the socio-scientific debate is resumed. In this phase, the questions from the first phase are reflected which were or were not clarified while learning the science behind. The fourth phase of learning about both society's handling of the issue and the inherent interplay between science and society focuses those questions which cannot be answered by science alone, it focuses the societal decision-making process about the socio-scientific issues, This phase is constructed by mimicking authentic societal practices. In the case of this project, a joint decision was made to apply either a role-playing exercise or a business game at this step of teaching. These approaches have already proved themselves to be valuable in a related pilot study on bioethanol use (Feierabend & Eilks, 2010, 2011a). The lesson plans finish with a meta-reflection phase, which focuses on the multidimensional learning process, and mimicking of the societal handling of the topic in the public debate, rather than simply on the topic and its evaluation.

Objectives	Criteria for selecting issues and approaches	Methods	Structure of the lesson plans
Allgemeinbildung/ education through science	Authenticity	Authentic media	1. Textual approach and problem analysis
(Multidimensional) Scientific Literacy	Relevance	Student oriented chemistry learning and lab-work	2. Clarifying the chemistry background in a lab environment
Promotion of evaluation skills	Evaluation undetermined in a socio-scientific respect	Learner centred instruction and cooperative learning	3. Resuming the socio-scientific dimension
Promotion of communication skills	Allows for open discussion	Methods structuring controversial debating	4. Discussing and evaluating different points of view
Learning science	Deals with questions from science and technology	Methods provoking the explication of individual opinions	5. Meta-reflection

Figure 3: The socio-critical and problem-oriented approach to chemistry teaching (Marks & Eilsk, 2009)

During the course of the project, one PAR group was established for each of four school subjects: biology, chemistry, physics, and politics education (Eilks et al., 2011a; Höttecke et al., 2010). Each group was composed of 5-8 teachers accompanied by 1-2 domain-specific university educators from the respective fields of study. The teachers came from different schools in the north of Germany and represented teaching practices in middle, grammar and comprehensive schools in both rural and municipal areas. The groups structured their lesson plans over a time period of about two years. On average they met once a month for one afternoon in order to structure the lesson plans and materials, and to report on and discuss their experiences.

The meetings were also used to acquaint the teachers with current scientific information on the issue of climate change. Participants increased their knowledge of available curriculum materials and potential school-type experiments from the domain-specific educational literature, which worked as inspiration for their curriculum planning efforts.

Table 1 provides an overview of the four lesson plans. The chemistry group example has already been described in more detail in Feierabend and Eilks (2010). All teaching materials have been completed and were already published as a resource book for teachers interested in teaching climate change in science classes, including those using interdisciplinary and project-based teaching approaches (Eilks et al., 2011b). The materials are still in operation in the participating schools. Parts of the materials later got implemented in a new German textbook for secondary chemistry education. Upon completion of the project, parts of the materials were adopted for use by the partners from the informal educational domain.

*Table 1: Overview of the lesson plans from the various projects (Eilks et al., 2011a)*

	Textual approach	Science content	Role-playing scenario
Biology	Authentic magazine cover and article	Internet search and jigsaw classroom on the relationship between food production and the emission of greenhouse gases	Role-playing a school's decision not to offer meat dishes anymore in the school cafeteria
Chemistry	Satirical YouTube video on the effects of climate change	Jigsaw classroom and experimental learning-at-stations lab on the use of conventional and renewable fuels for cars and their comparison	Role-playing/business game on raising the minimum driving license age to 21 years old to reduce the number of potential car drivers
Physics	Scientific presentation on climate change and its potential effects	Experimental learning-at-stations lab on heat absorption by gases, the radiation budget of the earth, and effects of temperature rises in the atmosphere	Role-play/business game on measures against the import of fruits brought to Europe by air transportation
Politics	TV report on the competition between food and fuel production	Reading informative texts about essential elements of the science background	Business game on establishing an embargo on the import of Brazilian bioethanol

Following the three-phase model of PAR, the lesson plans as whole (or single elements thereof) were individually pre-tested by members of the group. The members of the group were asked to report feedback mainly the feasibility of the structure and materials in terms of comprehensibility (based in impression, but also by collecting artifacts from the students' work), time management, and collecting spontaneous students' reactions towards the lessons. As part of phase 2 of the developmental model, broader testing took place after the first full proposal of each of the lesson plans was ready. In this phase, the lesson plans were taught parallel to one another in all four subjects mentioned above. Five different learning groups tested each lesson plan and represented a good blend of middle, grammar and comprehensive school classes from northern Germany. These twenty groups in the main testing cycle led to feedback from a total of 432 students. Student feedback was collected using questionnaires containing both open-ended and Likert-based items.

The questionnaires focused both the student perception of the lesson plan in its content and pedagogies as well as their reflection about learning success and a potential change in attitudes (Feierabend & Eilks, 2010). Additionally, pre- and post-group discussions were conducted in all learning groups. Both approaches focused upon lesson plan feasibility, students' viewpoints concerning climate change, and learner self-reflection on the decision-making process within the lesson plan. For later analysis of the course of the process, teacher feedback was also monitored by videotaping every AR group meeting. All data was then evaluated using qualitative content analysis (Mayring, 2002). Additional data was collected in order to better understand not only the domain-specific cultures of how to deal with evaluation competency, but also the changes in teachers' pedagogical content knowledge. Data from these additional studies will not be discussed in this paper.

### **Findings**

In the teacher discussions during the PAR group meetings, the deficiencies mentioned in the literature (see background of the project) were attested to by the participants, including the facets dealing with individual school environments. The teachers generally acknowledged the importance of this issue, but also affirmed a lack of adequate teaching materials. In line with the literature reviews, some teachers also mentioned feelings of insecurity when teaching climate change themselves, since they did not feel sufficiently confident in their content matter knowledge. The reason stated by the teachers was their awareness of climate change's undetermined nature as an issue and uneasiness at dealing with various, contradicting interpretations found in the public debate. They also stressed that their formal training as science teachers took place long before climate change ever became an issue of concern. Furthermore, in-service training focusing on multidimensional approaches to climate change was not available at that time. Teachers also felt a lack of sufficient support from textbooks and teaching materials. Here, they expressed their appreciation of the course the project took. The university input given as an update to their knowledge was very well-received, including not just the information about content, but also that dealing with available pedagogies and school-type experiments.

The teachers' participation in the project was acknowledged as being of great benefit for their teaching practice and continuous professional development. From the teachers' viewpoint, this project resulted in highly feasible teaching materials which they enjoyed including in their regular teaching. The teachers felt that the help from the university was very valuable for the joint developing of new teaching materials, but they also expressed satisfaction that their influence on the structure of the teaching materials had been acknowledged. Also, the involvement of different types of schools (grammar, middle and comprehensive schools from both rural and municipal areas) in the two subjects where this was the case (biology and chemistry) was considered to be beneficial, because this led to continuous reflection upon how the materials could be made as broadly applicable as possible. In the end, the teachers felt better-prepared to cope with difficult issues like climate change in their given subjects. Many of the teachers asked for further cooperation on both related and new issues. Altogether, the teachers reported a growth of personal expertise in the areas of content, methodology, and using experimental work in the classroom.

Concerning the lesson plans, the teachers reported classes in which their students were highly active. The developed lesson plans were thought to be an enrichment of the pedagogies that the teachers normally applied. Student feedback on the lesson plans was also very positive.

In the case of the chemistry questionnaire, pupils were asked about the lesson plan itself and their perceptions of it (see also Feierabend & Eilks, 2010). Nearly 70% of the students completely or predominantly agreed that they had enjoyed the lesson plan, because it dealt with content which personally interested them. A further 20% agreed partially to this same statement. Nearly 70% of the pupils agreed that they really liked the lesson plan's methods (again with about 20% agreeing partially), because learners could work out answers together with their classmates. Most students liked the business game element as part of science teaching, although this aspect is very unconventional in German science classrooms. Total agreement for this item was above 50%, partial agreement another 25%. The results were similar, with only slight variation in the other three subjects. Also in the open questionnaire, which was filled out before the Likert questionnaire, over 70% gave positive feedback on their own choices concerning different aspects of the lesson plan, i.e. the applied pedagogies.

From the viewpoint of the students, the lesson plans made them think more about climate change, with nearly 70% of the students at least predominantly agreeing with such a statement (another 25% partially agreeing). The chemistry students came predominantly from grade 9 comprehensive and middle school classes. Agreement was slightly lower in the other subjects, which were dominated by 10th grade grammar school classes. Perhaps the higher-achieving, older students in these courses felt themselves to be more self-reflective on this topic in advance to the lesson plan. Nevertheless, even among these groups between 45% (biology) and 60% (physics) of the learners fully or predominantly positively replied to this item, with another 30% in both groups agreeing at least partially, making up at least partially agreement - as in most of the other items - between some 70% to over 90%. Other items on this issue, e.g. whether students now saw the media debate with different eyes or whether their personal viewpoint towards climate change had altered, were also supported by roughly half the pupils with variations in the different subjects. Partial support was expressed by another 30% of the participants.

In both the pre- and post-group discussions, students recognized their responsibility for climate change on different levels (personal, political and economical). They saw a plurality of countermeasures for each level, even though the manner of argumentation differed quite widely (spontaneous vs. justified, reflective or constructive). Students were confronted with two dilemmas during the discussions: 1) a German city where pupils are forbidden to come to school by car (pre-discussion group) and 2) an EU-wide ban on conventional lightbulbs, including their immediate replacement with energy-saving lamps (post-discussion group). Learners were asked to list pros and cons for each situation, which decision-makers might be included and to state their own ideas of how such decisions should be handled. Starting with these two scenarios, intense discussions occurred in all of the groups. Overall, pre-group discussion was dominated by spontaneous, personal and often poorly-justified arguments. In the post-group discussions, the number of evidence-based arguments increased slightly (Feierabend, Stuckey, Nienaber, & Eilks, 2012).

#### **4. Reflection, discussion and implications**

Concerning teaching about climate change, the different PAR groups clearly supported the theoretical analysis that this issue has high potential for promoting student capabilities in communication, evaluation and decision-making. The joint reflection on the research evidence and teachers' classroom experience was valuable for making teachers aware of both their own deficits and restrictions and also their interests and needs (Feierabend & Eilks, 2011b).



This was an important starting point for sustainable innovation, since Huberman (1993) has already stated that any sustainable innovation in education must be bound to personal experience. In this case, it began with reflection on teachers' personal past experiences and was continuously linked to new experiences based on the newly-developed teaching approaches. The teachers also agreed that the units showed promise for dealing with climate change in science education in a multidimensional fashion. Results from both teacher and student feedback show that this potential was beginning to be realized in the initial steps. The collaborative and cyclical design plan led - in the estimation of the teachers and accompanying university science educators - to highly feasible, motivating lesson plans with a special focus on strengthening students' communication, evaluation and decision-making capabilities under inclusion of a societal perspective. Both the theoretical input from the accompanying educators, as well as the practical experience of the teachers contributed to the overall quality of the curriculum materials (Feierabend & Eilks, 2011b). Accompanying research gave a lot of insight on how to deal with the teaching climate change in domain-specific cultures, e.g. also about the role and potential benefits of using role play in the teaching of climate change. The lesson plan were thoroughly implemented in the participating schools and disseminated by several in-service science teacher trainings and a book with all the teaching materials (Eilks, et al. 2011b).

Within this project, two additional features were included beyond other PAR projects in the past (e.g. Eilks, Markic, & Witteck, 2010; Marks & Eilks, 2010). One was the interdisciplinary approach, the other the inclusion of partners from the informal educational domain (Feierabend & Eilks, 2011b). Compiling the results and bringing the teachers from the four groups together clearly showed the need for interdisciplinary approaches towards complex issues such as climate change. Nevertheless, initially working in parallel teams, then networking the different viewpoints and results proved itself to be a good strategy. It 1) allowed each group to become clear about their experiences and interests and 2) led to lesson plans feasible for individual syllabuses in individual subjects where administrative restrictions do not allow for interdisciplinary teaching (Feierabend & Eilks, 2011b). Nevertheless, the end product was a set of materials that can be combined in different ways for interdisciplinary or project-based approaches (Eilks et al. 2011b). The materials are now ready to integrate the science subjects under inclusion of a societal point-of-view. This provides a basis for new teaching strategies on climate change in German science education classrooms. The inclusion of politics also helped greatly, since this opened the project's focus and employed politics education pedagogies which also show promise for the area of science education. These experiences clearly support the idea that climate change as an issue requires a subject-integrated approach. This includes not just a combination of the different science teaching domains, but also other relevant subjects such as e.g. politics, education, or geography. Educational policy should take care not to restrict the teaching of complex issues by more holistic approaches through administrative barriers. This also includes too thoroughly compartmentalizing education by strictly dividing it into different school subjects and their respective syllabuses. On the other hand, the inclusion of partners from the informal educational domain did not have much influence on the curriculum development process within the project. However, we can recognize its still largely-unused potential for 1) increasing levels of exchange and cooperation between formal and informal education concerning curriculum development and 2) better educational networking and fine-tuning in both schools and informal education. Nevertheless, the inclusion of informal education partners gave us a second platform for implementation of part of the developed materials.

With respect to the teachers' professional development, the issue of climate change proved difficult to cover.

It is very uncommon for science teachers to deal with issues characterized by uncertainty, e.g. the continuous changes in scientific interpretations of available data, or rapidly changing political debates (Feierabend et al., 2011). Such aspects are quite commonly dealt with by teachers of politics. But the science teachers felt themselves able to cope with this challenge, thanks to the support of their diverse network of colleagues from different domains (Feierabend & Eilks, 2011b). Based on this experience, educational policy should more strongly support such multidimensional networks. It can acknowledge participation in such networks, for example by compensating the teachers with downtime for the time they spend working on project activities. Unfortunately, this was not the case for most of the teachers in this project, who had to sacrifice their time on a volunteer basis. PAR proved itself as a potentially beneficial structure for supporting such networking.

As part of teachers' continuous professional development, our experiences with PAR support the findings of similar projects, e.g. concerning the implementation of cooperative learning in chemistry education (Eilks et al., 2010) or the socio-critical and problem-oriented approach to chemistry teaching (Marks & Eilks, 2010). The value of PAR lies in its leading to a variety of lesson plans. These plans are widely accepted by the teachers as being authentic, well-tested and feasible, as we observed for the current examples of climate change lessons within this project (Feierabend & Eilks, 2011b). But PAR also contributed to teachers' CPD in the sense that it caused changes in the teachers' knowledge base, skills and attitudes as previously reported in Eilks (2003), Eilks and Markic (2011), or Mamlok-Naaman and Eilks (2012). The respective indications were also found within this framework.

For sustainable innovations in science education curricula and practice, we can recognize the overall value of establishing research based networks for close cooperation between educational researchers and practicing teachers (Huberman, 1993). Such partnerships are also operationalized in other approaches and methodologies (e.g. Putnam & Borko, 2000). Here, they proved once again that both sources of information about teaching practice are invaluable. Empirically validated research results and experientially-based teacher knowledge represent the two ends of a knowledge spectrum describing teaching and learning, and both are equally important in their own right (McIntyre, 2005). For educational policy, this and similar projects (Eilks et al., 2010; Feierabend & Eilks, 2011b; Marks & Eilks, 2010) yield clear support for our idea that more research-oriented partnerships between curriculum developers, educational researchers, and practicing teachers should be established for curriculum design and research. This would allow us to make use of all the resources that are available for teaching practice innovation in a networked environment. PAR as a research design strategy may help to uncover further potential for sustainable reform and implementation. These result because teachers' beliefs, their a priori knowledge and personal attitudes are all involved in such reforms and are taken into account seriously by the project. This is one of the essential basics for any successful, meaningful innovation in teaching practice, as has already been discussed by Haney, Czerniak and Lumpe (1996), Van Driel, Bulte and Verloop (2007), or Huberman (1993).

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## Productive Failure: From an Experimental Effect to a Learning Design

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Credits



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# 17. Productive failure: From an experimental effect to a learning design

Manu Kapur & Pee Li Leslie Toh

## Abstract

*Situating our work within the constructivist debate about effective ways of designing for learning, we describe our program of research on Productive Failure (PF), starting from the seminal work and tracing the developmental trajectory of designing for Productive Failure in classroom-based contexts. The PF learning design comprises a generation and exploration phase followed by a consolidation and knowledge assembly phase. PF affords students opportunities to activate and differentiate their prior knowledge so that they are better prepared to attend to and learn the critical conceptual features of the targeted concepts during the subsequent instruction. Our findings show that the PF learning design is more effective in developing conceptual understanding and transfer than a direct instruction design. Follow-up studies are described wherein key aspects of the productive failure design were tested over multiple classroom-based studies in Singapore public schools, and how these studies helped us interrogate and understand the criticality of key mechanisms embodied in the PF design.*

## 1. Introduction

Proponents of direct instruction bring to bear substantive empirical evidence against un-guided or minimally-guided instruction to claim that there is little efficacy in having learners solve problems that target novel concepts, and that learners should receive direct instruction on the concepts before any problem solving (Kirschner, Sweller, & Clark, 2006; Sweller, 2010). Kirschner et al. (2006) argued that “Controlled experiments almost uniformly indicate that when dealing with novel information, learners should be explicitly shown what to do and how to do it” (p. 79). Commonly-cited problems with un-guided or minimally-guided instruction include increased working memory load that interferes with schema formation (Sweller, 1988), encoding of errors and misconceptions (Brown & Campione, 1994), lack of adequate practice and elaboration (Klahr & Nigam, 2004), as well as affective problems of frustration and de-motivation (Hardiman, Pollatsek, & Well, 1986).

Consequently, this has led to a commonly-held belief that there is little efficacy in having learners solve novel problems that target concepts they have not learnt yet. Perhaps this belief is best captured by Sweller (2010), “What can conceivably be gained by leaving the learner to search for a solution when the search is usually very time consuming, may result in a suboptimal solution, or even no solution at all?” (p. 128). The basis for this belief comes from a large body of empirical evidence that has compared some form of heavily-guided direct instruction (e.g., worked examples) favorably with unguided or minimally-guided discovery learning instruction (Kirschner et al., 2006). It is of course not surprising that learners do not learn from unguided or minimally-guided discovery learning when compared with a heavily-guided direct instruction.

However, the conclusion that there is little efficacy in having learners solve problems that target concepts they have not learnt yet - something that they have to do in unguided discovery learning - does not follow.

To determine if there such an efficacy, a stricter comparison for direct instruction would be to compare it with an approach where students first generate representations and methods to novel problems on their own followed by direct instruction. It can be expected that the generation process will likely lead to failure. By failure, I simply mean that students will not be able to develop or discover the canonical solutions by themselves. Yet, what is critical is not the failure to develop the canonical solution per se but the very process of generating and exploring multiple representations and solution methods, which can be productive for learning *provided* direct instruction on the targeted concepts is subsequently provided (Kapur & Bielaczyc, 2012; Kapur & Rummel, 2009; Schwartz & Martin, 2004).

This chapter reports on a program of research that explores the possibility of affording learners the opportunity to engage in a process of generating solutions to novel problems, and shows how this process invariably leads to suboptimal solutions (that is, failure to generate the canonical solutions) but can still be a productive exercise in failure provided some form of direct instruction follows (Kapur, 2010, 2011, 2012). Thus argued, instead of reporting experiments comparing discovery learning with direct instruction, the work presented herein seeks to understand whether combining the two - as instantiated in the learning design called *productive failure* (Kapur & Bielaczyc, 2012) - can be more effective than direct instruction alone.

We start with a brief review of research that supports the case for productive failure, and points to an efficacy of learner-generated solutions provided an appropriate form of direct instruction builds upon it. Next, we provide a brief description of the mechanisms embodied in the design principles of productive failure. Following this, we describe a program of design research wherein key aspects of the productive failure design were tested over multiple classroom-based studies in Singapore public schools. Our aim is not to describe each study in detail. Instead it is to articulate the underlying logic of how the various studies help us test and understand some of the critical design decisions of PF.

## **2. The case for of failure in learning and problem solving**

Research on *impasse-driven learning* (Van Lehn, Siler, Murray, Yamauchi, & Baggett, 2003) with college students in coached problem-solving situations provides strong evidence for the role of failure in learning. Successful learning of a principle (e.g., a concept, a Physical law) was associated with events when students reached an impasse during problem solving. Conversely, when students did not reach an impasse, learning was rare despite explicit tutor-explanations of the target principle. Instead of providing immediate or direct instruction upfront, e.g., in the form of feedback, questions, or explanations, when the learner demonstrably makes an error or is “stuck,” Van Lehn et al.’s (2003) findings suggest that it may well be more productive to delay that instruction up until the student reaches an impasse - a form of failure - and is subsequently unable to generate an adequate way forward.

Building on this, Mathan and Koedinger (2003) compared learning under two different feedback conditions on student errors. In the immediate feedback condition, a tutor gave immediate feedback on student errors. In the delayed feedback condition, the tutor allowed the student to detect their own error first before providing feedback.

Their findings suggested that students in the delayed feedback condition demonstrated a faster rate of learning from and on all the subsequent problems. Delayed feedback on errors seemed to have resulted in better retention and better preparation to learn from subsequent problems (Mathan & Koedinger, 2003).

Further evidence for such *preparation for future learning* (PFL; Schwartz & Bransford, 1998) can be found in the *inventing to prepare for learning* (IPL) research by Schwartz and Martin (2004). In a sequence of design experiments on the teaching of descriptive statistics with intellectually gifted students, Schwartz and Martin (2004) demonstrated an existence proof for the hidden efficacy of invention activities when such activities preceded direct instruction, despite such activities failing to produce canonical conceptions and solutions during the invention phase. However, the proponents of direct instruction have criticized PFL and IPL studies because of a lack of adequate control and experimental manipulation of one variable at a time, which makes it difficult to make causal attributions of the effects (Kirschner et al., 2006).

Earlier experiments in *productive failure* (Kapur, 2008) provide evidence from randomized-controlled experiments for the role of failure in learning and problem by delaying structure. Kapur (2008) examined students solving complex problems without the provision on any external support structures or scaffolds. 11<sup>th</sup>-grade student triads from seven high schools in India were randomly assigned to solve either ill- or well-structured physics problems in an online, chat environment. After group problem solving, all students individually solved well-structured problems followed by ill-structured problems. Ill-structured groups generated a greater diversity of representations and methods for solving the ill-structured problems. However, ill-structured group discussions were found to more complex and divergent than those of their well-structured counterparts, leading to poor group performance (Kapur, 2011a; Kapur, Voiklis, Kinzer, & Black, 2006). Notwithstanding, findings suggested a hidden efficacy in the complex, divergent interactional process even though it seemingly led to failure. Kapur argued that delaying the structure received by students from the ill-structured groups (who solved ill-structured problems collaboratively followed by well-structured problems individually) helped them discern how to structure an ill-structured problem, thereby facilitating a spontaneous transfer of problem-solving skills. Findings from this study have since been replicated (Kapur & Kinzer, 2009).

These findings are consistent with other research programs that suggest that conditions that maximize performance in the shorter term are not necessarily the ones that maximize learning in the longer term (Clifford, 1984; Schmidt & Bjork, 1992). Collectively, it is reasonable to reinterpret their central findings as all of them point to the efficacy of learner-generated processing, conceptions, representations, and understandings, even though such conceptions and understandings may not be correct initially and the process of arriving at them not as efficient. The above findings, while preliminary, underscore the implication that by delaying instructional support - be it explanations, feedback, direct instruction, or well-structured problems - in learning and problem-solving activities so as to allow learners to generate solutions to novel problems can be a productive exercise in failure (Kapur, 2008).

More than simply indicating a delay of instructional structure, these studies also underscore the presence of desirable difficulties and productive learner activity in solving problems. It is this interest in what is present, that is, the features of productive learner activity (even if it results in “failure”), that forms the core of our work. Based on the literature and our own studies in PF, we have begun to develop a design theory of what needs to be present in student problem-solving contexts in which instructional structure is delayed. We are interested in testing our theoretical conjectures by investigating their embodiment in the design of problem-solving experiences that, although leading to short-term performance failure, are efficacious in the longer term. We briefly describe these design principles and the theoretical conjectures they embody next (for a fuller description, see Kapur & Bielaczyc, 2012).

### **3. Designing for productive failure (PF)**

There are at least two problems with direct instruction in the initial phase of learning something new or solving a novel problem. First, students often do not have the necessary prior knowledge differentiation to be able to discern and understand the affordances of the domain-specific representations and methods underpinning the targeted concepts given during direct instruction (e.g., Kapur & Bielaczyc, 2012; Schwartz & Bransford, 1998; Schwartz & Martin, 2004). Second, when concepts are presented in a well-assembled, structured manner during direct instruction, students may not understand why those concepts, together with their representations, and methods, are assembled or structured in the way that they are (Chi, Glaser, & Farr, 1988; Schwartz & Bransford, 1998).

Cognizant of these two problems, PF engages students in a learning design (for a fuller explication of the design principles, see Kapur & Bielaczyc, 2012) that embodies four core, interdependent mechanisms: a) activation and differentiation of prior knowledge in relation to the targeted concepts, b) attention to critical conceptual features of the targeted concepts, c) explanation and elaboration of these features, and d) organization and assembly of the critical conceptual features into the targeted concepts. These mechanisms are embodied in a two phase design: a generation and exploration phase (Phase 1) followed by a consolidation phase (Phase 2). Phase 1 affords opportunities for students to generate and explore the affordances and constraints of multiple representations and solution methods (RSMs). Phase 2 affords opportunities for organizing and assembling the relevant student-generated RSMs into canonical RSMs. The designs of both phases were guided by the following core design principles that embody the abovementioned mechanisms:

- (1) create problem-solving contexts that involve working on complex problems that challenge but do not frustrate, rely on prior mathematical resources, and admit multiple RSMs (mechanisms a and b);
- (2) provide opportunities for explanation and elaboration (mechanisms b and c);
- (3) provide opportunities to compare and contrast the affordances and constraints of failed or sub-optimal RSMs and the assembly of canonical RSMs (mechanisms b-d).

### **4. Examining the PF design in the real ecologies of Singapore classrooms**

Having articulated the mechanisms embodied in the design principles of PF, we now describe the implementation in a series of classroom-based experiments. To bring about change in classroom practice and pedagogy, especially in a system of high-stakes testing such as Singapore, it was important to compare a new learning design (e.g., PF) with a design most prevalent in practice (e.g., DI). Thus, we started by comparing learning from PF with DI.

We illustrate a comparison of learning from PF and DI through a pre-posttest, quasi-experimental study (hereinafter referred to as Study 1) with 133, ninth-grade mathematics students (14-15 year olds) from a public school in Singapore (for fuller details, see Kapur, 2012). The targeted concept was Standard Deviation (SD), which is typically taught in the tenth grade, and therefore, students had no instructional experience with the targeted concept prior to the study.

All students, in their intact classes, participated in four, 50-minute periods of instruction on the concept as appropriate to their assigned condition. The same teacher taught both the PF and DI conditions.

In the PF condition, students spent the first two periods working face-to-face in triads to solve a complex data analysis problem on their own (see Appendix A). The data analysis problem presented a distribution of goals scored each year by three soccer players over a twenty-year period. Students were asked to design a quantitative index to determine the most consistent player. During this generation phase, no cognitive guidance or support was provided. In the third period, the teacher first consolidated by comparing and contrasting student-generated solutions with each other, and then modeled and worked through the canonical solution. In the fourth and final period, students solved three data analysis problems for practice, and the teacher discussed the solutions with the class.

In the DI condition, the teacher used the first period to explain the canonical formulation of the concept of variance using two sets of “worked-example followed by problem-solving” pairs. The data analysis problems required students to compare the variability in 2-3 given data sets, for example, comparing the variability in rainfall in two different months of a year. After each worked example, students solved an isomorphic problem, following which their errors, misconceptions, and critical features of the concept were discussed with the class as a whole. To motivate students to pay attention and remain engaged, they were told that they will be asked to solve isomorphic problems after the teacher-led worked examples. In the second period, students were given three isomorphic data analysis problems to solve, and the solutions were discussed by the teacher. In the third period, students worked in triads to solve the same problem that the PF students solved in the first two periods, following which the teacher discussed the solutions with the class. DI students did not need two periods to solve the problem because they had already learnt the concept. The DI cycle ended with a final set of three data analysis problems for practice (the same problems given to the PF students), which the students solved individually, and the teacher discussed the solutions with the class.

Process findings suggested that PF groups generated on average six solutions to the problem. Elsewhere (see Kapur, 2012), we have described these student-generated solutions in greater detail. For the present purposes, we only briefly describe the four categories of solutions:

- a. *Central tendencies* (e.g., using mean, median, mode).
- b. *Qualitative methods* (e.g., organizing data using dot diagrams, frequency polygons, line graphs to examine clustering and fluctuations patterns).
- c. *Frequency methods* (e.g., counting the frequency with which a player scored above, below, and at the mean to argue that the greater the frequency at the mean relative to away from the mean, the better the consistency).
- d. *Deviation methods* (e.g., range; calculating the sum of year-on-year deviations to argue that the greater the sum, the lower the consistency; calculating absolute deviations to avoid deviations of opposite signs cancelling each other; calculating the average instead of the sum of the deviations).

None of the PF groups were able to generate the canonical formulation of SD. In contrast, analysis of DI students’ classroom work revealed that students relied *only* on the canonical formulation to solve data analysis problems. This was not surprising given that had been taught the canonical formulation of SD, which is also easy to compute and apply. All DI students were accurately able to apply the concept of SD to solve the very problem that the PF students tried to generate a solution to.

Furthermore, the solutions generated by PF students suggested that not only were students’ priors activated (central tendencies, graphing, differences, etc.) but that students were able to assemble them into different ways of measuring consistency.

After all, PF students could only rely on their priors -formal and intuitive -to generate these solutions. Therefore, the more they can generate, the more it can be argued that they are able to conceptualize the targeted concept in different ways, that is, their priors are not only activated but also differentiated in the process of generation. In other words, these solutions can be seen as a measure, albeit indirect, of knowledge activation and differentiation; the greater the number of such solutions, the greater the knowledge activation and differentiation.

On the day immediately after the intervention, all students took a posttest comprising three types of items: procedural fluency, conceptual understanding, and transfer (for the items, see Kapur, 2012). Analysis of pre-post performance suggested that PF students significantly outperformed their DI counterparts on conceptual understanding and transfer without compromising procedural fluency. Further analyses revealed that the number of solutions generated by PF students was a significant predictor of how much they learnt from PF. That is, the more solutions they students generated, the better they performed on the procedural fluency, conceptual understanding, and transfer items on the posttest. We refer to this effect as the *solution generation effect*.

### **Discussion**

These findings are consistent with the seminal studies on productive failure (Kapur, 2008; Kapur & Kinzer, 2009), and also with other studies described earlier (e.g., Schwartz & Bransford, 1998; Schwartz & Martin, 2004). These findings suggest that there is in fact a utility in having students solve novel problems first. To explain these findings, we argued that the PF design invoked learning processes that not only activated but also differentiated students' prior knowledge as evidenced by the number of student-generated solutions. Whereas PF students were afforded opportunities to work with not only the solutions that they generated but also the canonical solutions that they received during direct instruction, DI students worked with only the canonical ones. Hence, DI students worked with a smaller number of solutions, and consequently, their knowledge was arguably not as differentiated as their PF counterparts.

What prior knowledge differentiation affords in part is a comparison and contrast between the various solutions - among the student-generated solutions as well as between the student-generated and canonical solutions. Specifically, these contrasts afford opportunities to attend to the following critical features of the targeted concept that are necessary to develop a deep understanding of the concept. Granted that student-generated solutions are at best an indirect measure of prior knowledge activation and differentiation, it was nonetheless a critical difference between the two conditions by design. Importantly, this difference needs to be situated in the argument made by the proponents of DI in their questioning of the utility of getting students to generate solutions to solve novel problems on their own.

They argue that students should be given the canonical solutions (either through worked examples or direct instruction) before getting them to apply these to solve problems on their own (Sweller, 2010).

### **5. Further studies examining the PF design**

On the one hand, the finding that the more solutions students generate, the more they learn from PF on average -the solution generation effect - evidenced one of the key mechanisms of the PF design of prior knowledge activation and differentiation. On the other hand, the solution generation effect also raised important questions for further inquiry. In this section, we describe four such lines of inquiry; each testing a critical aspect of the PF design.



Once again, fuller descriptions of these studies can be found in our published work, and therefore, our intention here is to briefly describe and summarize the findings and their implications for the PF design.

### **The role of math ability**

A key assumption in the PF design is that students have the formal and intuitive resources for generation and exploration prior to learning a new concept. In the light of the solution generation effect, an obvious and immediate question given was to examine the role of math ability. After all, one could expect math ability to influence what and how much students generate, and consequently how much students learn from PF.

Testing the efficacy of PF over DI across different math ability profiles was precisely the aim of the studies reported in Kapur and Bielaczyc (2012). Students were purposefully sampled from three public, co-educational schools with significantly different math ability profiles - 75 high ability, 114 medium ability, and 113 low ability - on the national standardized examinations in Singapore. In each school, students in their intact classes were assigned to the PF or the DI condition taught by the same teacher.

Several key findings were demonstrated: a) the relative efficacy of PF over DI was replicated, b) the solution generation effect was replicated, and c) students with significantly different math ability were not as different in terms of their capacity to generate solutions during the generation and exploration phase. Consequently, students across different ability profiles were able to learn better from PF than DI. Taken together, these findings provided a strong evidence for the design principles of PF, and demonstrated the tractability of PF across a range of math ability provided one is able to design according to the design principles of PF.

### **The role of guided versus unguided generation**

A critical design decision for PF is to not provide cognitive guidance or support during the generation and exploration phase. The solution generation effect showed that students of different math abilities are in fact able to leverage their formal and intuitive resources to generate solutions even in the absence of any cognitive guidance or support. However, this only begged the question: might not guiding students during the generation and exploration phase result in an even better production of solutions, which in turn may help students learning even more from PF? In other words, what is the marginal gain of providing students with guidance during the generation and exploration phase?

In Kapur (2011b), we addressed this question. Participants were 109, Secondary 1 (grade 7) students from a co-educational public school in Singapore. Students were from three mathematics classes taught by the same teacher. The participating school was a mainstream school comprising average-ability students on the grade six national standardized tests. The same study design as in Study 1 was used except that in addition to the PF and DI conditions, a third condition - the guided generation condition - was added. One class was assigned to each condition. The guided-generation condition was exactly the same as the PF condition but with one important exception.

Whereas students in the PF condition did not receive any form of cognitive guidance or support during the generation and exploration phase, students in the guided-generation condition were provided with cognitive support and facilitation throughout that process. Such guidance was typically in the form of teacher clarifications, focusing attention on significant issues or parameters in the problem, question prompts that engendered student elaboration and

explanations, and hints towards productive solution steps (Hmelo-Silver, Duncan, & Chinn, 2007; Puntambekar & Hübscher, 2005).

Findings suggested that students from the PF condition outperformed those from the DI and guided-generation conditions on procedural fluency, conceptual understanding and transfer. The differences between guided-generation and DI conditions were not significant, though students from the guided-generation condition performed marginally better than those from the DI condition. Overall, the descriptive trend  $PF > \text{guided-generation} > LP$  seemed consistent across the different types of items. We argued that giving guidance too early or in the process of generation does not add to the preparatory benefits of generation in part because students may not be ready to receive and make use of the guidance provided.

### **The role of generating versus studying and evaluating solutions**

A critical mechanism embodied in the PF design is one of generation and exploration of solutions relying only on students' formal and intuitive resources. However, it was not clear from the solution generation effect whether what was critical is the generation of solutions or simply an exposure to these solutions. Simply put, is it really necessary for students to generate the solutions or can these solutions be given to students to study and evaluate, that is, the opportunity to learn from the failed problem-solving efforts of their peers? We refer to learning from the failed problem-solving efforts of others as learning from *Vicarious Failure* (VF). If productive failure is a design where students have an opportunity to learn from their own failed solutions, then vicarious failure is a design where students have an opportunity to learn from the failed solutions of their peers.

In Kapur (in press-a), we compared the effectiveness of learning from PF and VF. Participants were one hundred and thirty six ( $N = 136$ ) grade eight mathematics students (14-15 year olds) from two co-educational public schools in Singapore. Sixty four students from School A and seventy two students from School B participated in the study. In both the schools, students came from two intact classes taught by the same teacher. As per the PF design, PF students experienced the generation and exploration phase followed by the consolidation and knowledge assembly phase. VF students differed from the PF condition only in the first phase: The generation and exploration phase was replaced with a study and evaluate phase, where instead of generating and exploring solutions, students worked in small groups to study and evaluate student-generated solutions (available from earlier work, e.g., Kapur, 2012; see Kapur, in-press for examples of solutions). VF students then received the same consolidation and knowledge assembly as PF students. In the study and evaluation phase for VF students, students first read the complex problem (see Appendix A) and were then presented with the student-generated solutions one-by-one counterbalanced for order with the prompt: "Evaluate whether this solution is a good measure of consistency. Explain and give reasons to support your evaluation." The number of solutions was pegged to the average number of solutions produced by PF groups, that is, six. The most frequently-generated solutions by the PF students were chosen for VF condition.

Findings suggested that, after controlling for prior knowledge, school, and ability differences, PF students significantly outperformed VF students on conceptual understanding and transfer, without compromising procedural fluency. These findings underscored the primacy of generation over mere exposure, thereby evidencing a key mechanism of the PF design. In more recent work (Kapur, in-press-b), we have compared PF, VF, and DI, and shown the findings to be consistent with Kapur (in-press-a).

### **The role of attention to critical features**

As discussed earlier, the contrasts among and between the student-generated solutions and the canonical solutions afford students the opportunities to attend to the critical features of the targeted concept. However, if what is essential is that students attend to the ten critical features, then why not simply tell students these critical features? Why bother having them generate, and compare and contrast the solutions? Simply put, do students really need to generate before receiving the critical features, or would telling the critical features without any generation work just as well? Addressing this question would help understand a critical mechanism of PF that the generation and exploration of solutions better prepares students to understand the critical features during for instruction than simply telling them those features.

In Kapur and Bielaczyc (2011), we addressed this question. Participants were 57, ninth-grade mathematics students (14-15 year olds) from two intact classes in an all-boys public school in Singapore. One class was assigned to the PF condition, and the other class to the 'Strong-DI' condition. Both classes were taught by the same teacher. The PF condition was exactly the same as in Study 1. The Strong-DI condition was the same as the DI condition in Study 1 except that the teacher drew attention to the ten critical features during instruction (e.g., why deviations need to be taken from the mean, why they must be positive, why divide by  $n$ , etc.). While explaining each step of formulating and calculating SD, the teacher explained the appropriate critical features relevant for that step. For example, when explaining the concept of "deviation of a point from the mean", the teacher discussed why deviations need to be from a fixed point, why the fixed point should be the mean, and why deviations must be positive. During subsequent problem solving and feedback, the teacher repeatedly reinforced these critical features throughout the lessons.

Findings suggested that PF students significantly outperformed their Strong-DI counterparts on conceptual understanding without compromising on procedural fluency. There were no differences in terms of transfer. These findings suggested that although telling students novel information can be effective, the generation and exploration phase is nonetheless better in preparing students to receive these features.

## **6. Conclusion**

Contrary to the commonly-held belief that there is little efficacy in having learners solve novel problems that target concepts they have not learnt yet, our work suggests that there is indeed such an efficacy even if learners do not formally know the underlying concepts needed to solve the problems, and even if such problem solving leads to failure initially.

In this chapter, we traced the developmental trajectory of PF from its inception to a learning design. We started by describing the mechanisms embodied in the PF design, as well as the principles guiding the design. Our initial work in the schools compared the PF design with the most prevalent design in classroom instruction, that is, DI.

Findings from an initial comparison between PF and DI were encouraging, yet raised further lines of inquiry that necessitated a closer examination of some critical aspects of the PF design, namely: a) the role of math ability, b) the role of guidance during the generation, c) the role of learning from vicarious failure, and d) the role of attention to critical features. Each of these lines of inquiry was pursued through classroom-based quasi-experimental studies.

Thus far, our work has focused on a closer interrogation of the design to more systematically unpack and examine its design assumption and decisions.

Through such an “iterative” examination in real-ecologies, our goal for the PF learning design is to become more “ecologically valid and practice-oriented” (Confrey, 2006, p. 144). More importantly, the iterative examination of the design further generates theoretical conjectures that in turn drive future work. In other words, the continuous examination of the design enables the development of possible design principles that direct, apprise and advance educational research and practice (Anderson & Shattuck, 2012). Therefore, our future work would continue to interrogate the PF design and all its constituent mechanisms, design principles, and design decisions, while at the same time iterate and refine the PF design.

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## Boundary Objects in Educational Design Research: Designing an Intervention for Learning How to Learn in Collectives with Technologies that Support Collaboration and Exploratory Learning

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# 18. Boundary objects in educational design research: Designing an intervention for learning how to learn in collectives with technologies that support collaboration and exploratory learning

Nikoleta Yiannoutsou & Chronis Kynigos

## Abstract

*In this chapter we address Educational Design Research in Technology Enhanced Learning as an interdisciplinary task where various expertise and hybrid actors are required. Specifically, we describe the research process of developing an intervention that integrates technology in teaching 12-16 year old students to “learn how to learn together” Mathematics, Newtonian Physics and the concept of sustainability in the context of Environmental studies. In the design of this intervention we involved people from the following communities: educationalists – academics and practitioners- technology experts. To facilitate communication, shared understanding and meaningful contribution from the different experts we used the concept of boundary objects as instruments supporting shared understanding through boundary crossing between the communities. Thus the focus of this chapter is to describe the research process through which we designed the pedagogical intervention with the use of boundary objects employed to integrate interdisciplinary knowledge. Thus, boundary objects are neither the output nor the focus of intervention but a set of tools supporting it. The intervention we designed was developed and evaluated in four educational systems (Greece, UK, Spain and Israel). The output of the intervention is ten pedagogical activities and a set of design guidelines. Our research is in progress and thus, the assessment of the intervention output (scenarios - design guidelines) and of the boundary objects is not included in this chapter.*

## 1. Introduction

Technology, design and teaching are described as the most representative professional domains which require a high degree of specialization and cross-sectional work (Akkerman & Bakker, 2011). Boundary objects function as bridges between the different domains / disciplines involved in a task. “They are both adaptable to different viewpoints and robust enough to maintain identity across them, they have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable” (Star & Griesemer, 1989 pp. 393) Boundary objects have the following characteristics: a) they are designed to articulate meanings and express different perspectives b) they facilitate a back and forth movement between the different disciplines involving well-structured use in local site work and ill-structured use in cross site work (Akkerman & Bakker, 2011) and c) their status is based on fallibility; an epistemological approach where artifacts are considered as malleable, questionable and improvable (Kynigos, 2007). A typical example of a boundary object offered by Akkerman and Bakker (2011) is a patient’s record that is used by different departments and institutes in medical care.

The example of Educational Design Research (here after EDR) we report here is in the field of Technology Enhanced learning and involves the design of a pedagogical intervention. The design of this intervention requires effective involvement of educationalists-academics and practitioners -and of technology experts. To facilitate this process we designed three boundary objects (see design specifications section) and we employed them in our research as artifacts/tools with the aim to help us integrate in our intervention the expertise from the different fields through negotiation, change and improvement. Thus, the boundary objects are described here rather as tools facilitating EDR than as output of this intervention.

The focus of our research is to design a pedagogical intervention which aims at supporting students to learn how to learn together concepts in specific domains, by exploiting technologies that support collaboration and exploratory learning (see next section for the conceptualization of the problem). Learning in a group is not only about being able to work with others but it also involves functioning at a meta-level which entails awareness and regulation by the group of the parameters influencing collaborative learning. To capture both dimensions of collaborative learning -i.e. learning as a member of a group and also operating at the meta-level of facilitating group-work- we use the term “Learning to Learn Together” (here after L2L2) advocated by Wegerif (2013). In the field of Computer Supported Collaborative Learning (here after CSCL) there is work relative to L2L2 which involves the regulation of collaboration (see for example Dekker et al 2006). CSCL scripts (Dillenbourg 2002) build -on the idea of helping students to regulate their collaborative work by structuring the situations in which collaboration takes place or by regulating the interaction as it unfolds. Our approach builds on this work by elaborating on the skills involved in L2L2 (i.e. mutual engagement, distributed leadership, peer assessment and group reflection; for a detailed description see Wegerif, 2013) and by designing technologies and pedagogical interventions to teach students these skills (ibid) In this chapter we discuss a study where our research question was formulated as follows:

*How can we teach 12-16 year old students to learn how to learn together using technologies designed to support constructionist - experiential domain learning in combination with collaboration and argumentation tools?*

To address this question we designed pedagogical interventions in realistic classroom situations based on the use of technology that supports collective experiential learning (we call it the META-FORA Platform). This intervention aimed for the development of pedagogical activities (including teaching and learning materials) with the use of the META-FORA platform which was under development itself. A special aspect of our task was that there were no explicit curriculum guidelines for this particular kind of learning in any of the four European countries in which we designed our interventions. We thus worked within the paradigm of EDR (Nieveen 2009) in order to ground our initial designs in theory and then we followed a process of micro-evaluations which lead back to theory and refinement of our designs. Our target outcome with respect to what we describe in this chapter was a set of ten designs of pedagogical activities and the articulation of related design principles for activity design for L2L2.

The design-development phase, on which we focus, lasted 18 months and was implemented in five stages (Figure 1). In the first stage we built on the state of the art knowledge on collaborative learning and meaning generation mediated by digital technologies (version 1-stage 1). In the next stages we refined the intervention using the following “filters”: a) the progressively available functionalities of the META-FORA Platform which was being concurrently designed

and developed (version 2,4) b) observations of student and teacher activity (versions 3, 4 and 5)  
 c) teacher reflections on their activity (version 5).

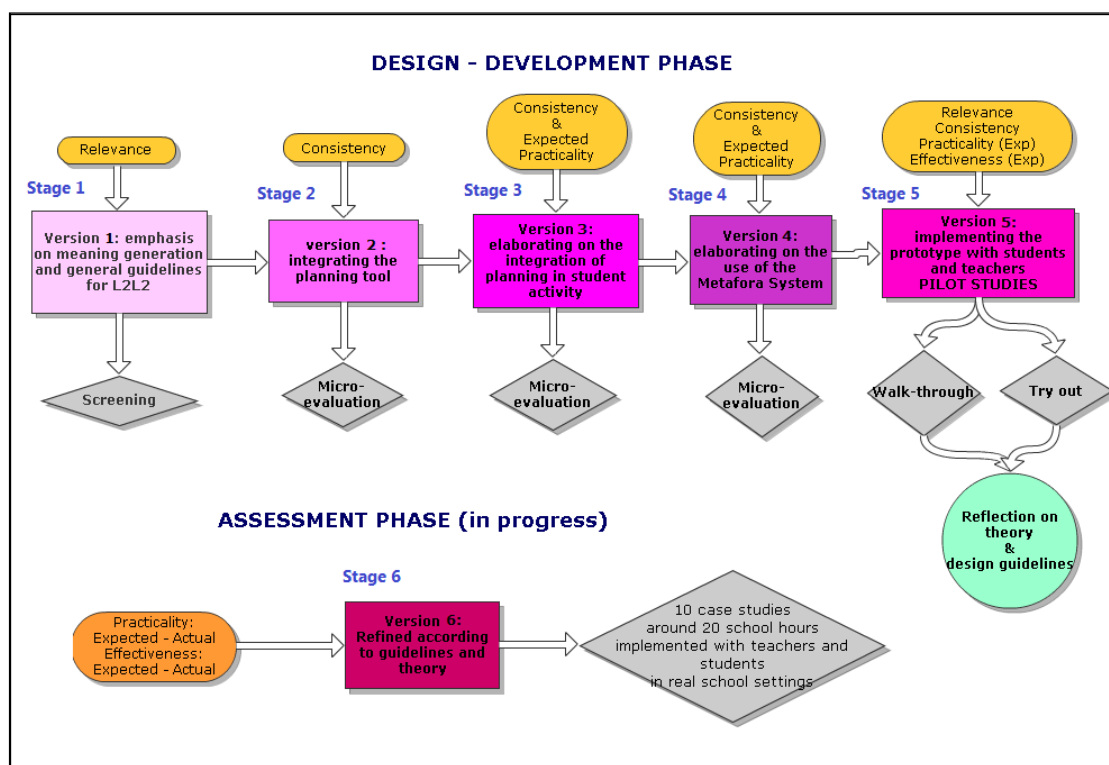


Figure 1: Development of the prototype: versions, criteria and formative evaluation methods as described in Nieveen (2009)

Four research groups (See “Key Sources” for a list of the participants) participated in the research, with expertise in introducing digital technologies in the school system each of which adopted different and complementary theoretical backgrounds. Each Research group had established links with schools, students and teachers (in-service and graduate). The Design - Development phase (see Figure 1) involved the participation of educational researchers, technology experts (see “Key Sources”) in-service and graduate teachers, students and schools. The structure of this chapter follows the progress of our research presenting how the intervention was originally conceived and then how the different stages of design based research informed the refinement of the various versions of the prototype.

## 2. Conceptualization of the intervention: Situating learning to learn together

Process-oriented approaches have studied both individual learning (problem solving, meaning generation) and learning in collectives (collaborative learning). Both have been criticized for a lack of focus on what is being learned, i.e. on meanings generated around a powerful idea or an elusive concept (Papert, 2005). Approaches focusing on the learning of specific concepts on the other hand have been criticized for their lack of relevance to students' interests, on the de-contextualized nature of learning a concept in the abstract and on the lack of students' ability to transfer their understanding from one context to another (Wegerif 2013). There is some literature relating collaborative work with group effectiveness on the task (Jansen, Erkens,

Kirschner, & Kanselaar, 2010) or relating subject matter with the social practices and norms (Yackel & Cobb, 1996; Stahl, 2007) We build on this work focusing on the meta level of collaborative learning - i.e. L2L2 - aiming to investigate a) how the social practices and norms of the different subject matters might influence the process of L2L2 and b) how this process is shaped by the affordances of the exploratory tools.

Designing interventions where learners find themselves in collectives trying to develop collaborative skills and at the same time making sense of a powerful idea as part of a difficult challenge they are faced with as a group are recently gaining in importance. This is because society and the workplace of the knowledge age show that collaboration has become more demanding as people situated in different places with different backgrounds and expertise need to work and learn together (for an illustrative analysis of an example see Wegerif et al., 2012).

In our research we wanted to design interventions in realistic school situations where students would be encouraged to meet difficult problems involving the understanding of powerful ideas and to address those problems in groups. Our approach was distinct in the sense that it was based on constructionism, i.e. students collectively tinkering with digital models used in the role of expressive media (Kynigos, 2012). We designed a set of interventions each involving a particular domain and students' use of a corresponding set of digital models embedding powerful ideas from that domain. The domains we chose were Mathematics, Newtonian physics and Sustainability within an Environmental Studies framework. We opted for this range of domains to try to make some sense of how our designs might change in relation to the epistemological approach in each case. In Mathematics education for example, particular emphasis is given to cognitive tools for abstraction and generalization (Mavrikis et al, 2011). In Science education, the focus is on phenomenology (DiSessa, 2000) while in environmental studies education emphasis is given to action competencies and in becoming more aware of the complexity and diverse approaches to environmental issues (Kynigos & Daskolia, 2011).

### **3. Design specifications through boundary objects: Scenarios, scenario profiles and implementation protocols**

The rationale underlying our design addresses the design and development of the intervention as an interdisciplinary task where pedagogical knowledge of the academics is integrated with the knowledge of the practitioners and of technology experts (see Figure 2 where the three different communities - Academics, Practitioners and Technology Experts - are depicted with different colors). This integration would allow us to a) ground the intervention on the state of the art of technology enhanced learning b) design uses of technology which make the most out of its functionalities and best support the aims of the intervention and c) make the designed uses fit to be implemented in real classroom settings in a way that meets the characteristics of the different contexts across sites.

The members of the different communities shared a common goal which was to engage students in learning to learn together mathematics, sciences and the concepts in the field of environmental education (i.e. domain learning) with the use of technology (i.e. the META-FORA Platform). This common goal is depicted at the centre of Figure 2 and was negotiated among the different communities with the three boundary objects we constructed in order to inform and concretize our intervention: a) the description of the pedagogical activities that were expected to be carried out during the intervention (Scenarios) b) the rationale underlying the decision on these actions which involves grounding design to theory (Scenario profiles) and c) the context for which these actions were designed which involves situating design in real settings and

offering input for its implementation (Implementation protocols). These three elements were further developed to form three sets of design specifications.

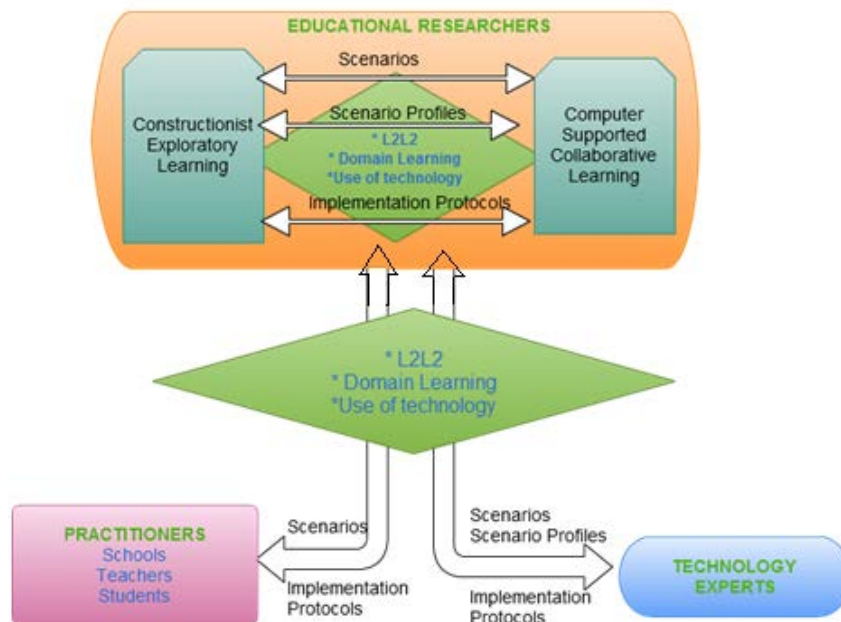


Figure 2: The different perspectives/disciplines involved in the design and the boundary objects- scenarios, scenario profiles and implementation protocols- facilitating expression of meanings from the different communities

Scenarios and Implementation protocols -as shown in Figure 2 supported -collaboration among academics and practitioners around the idea of the intervention (scenario) and the specifics of the implementation (implementation protocol) The same boundary objects were used to communicate to the Technology Experts how the technology was intended to be used (scenario) and in which context (implementation protocol). Scenario profiles were also used among educational researchers and Technology experts in order to justify design decisions or request the implementation of new functionalities.

Figure 2 indicates the existence of two different entities within the community of educational researchers and this is because the pedagogical knowledge in this intervention involved two different theoretical approaches on learning: one represented by the CSCL community and the other by the Constructionist Exploratory Learning community. These two communities address learning from different perspectives. CSCL community on the one hand focuses on the social dimension of learning irrespectively of the subject matter, whereas Constructionist - Exploratory learning community focuses on the learning process in relation to the concepts of specific scientific fields. Both communities are engaged in studying the use of technology to support L2L2 in specific domains but the different view-points create a boundary which marks a discontinuity in the emphasis of the methods of teaching and in the focus of learning: in the first case collaboration is the objective whereas in the second case collaboration is the means. These different perspectives –also within the pedagogical domain - were expected to evolve around the central concepts of the intervention: i.e. L2L2, domain learning and use of

technology to support the above (Figure 2) and were elaborated through the use of the three boundary objects.

### **Scenarios: tools to describe the process of implementing the intervention**

The first set of design specifications defined what we called scenario (see Kynigos & Kalogeria, 2012 for an elaboration). The scenario describes the main elements of a plan of pedagogical activity which employs the use of technology, intertwines domain learning with L2L2 objectives and allows for a significant investigation (15-20 school hours). The scenario addresses aspects related to the epistemology of the domain, social orchestration, role and use of the tool, duration and what we call “suggested didactical sequence”. The latter describes in detail the designer’s intentions in terms of what the teachers and the students are expected to do during the implementation of the scenario in the classroom. Assessment suggestions are also included in the scenario. Ten different scenarios were produced by the researchers of the four research groups to support learning how to learn together mathematics, Physics and concepts about sustainability (See the section describing Stage 1 in Design Development Phase for a table with a list of scenarios). The main structure of the scenario was captured in what we called “Scenario Templates” which include the design specifications for the description of the scenarios (see Deliverable D.3.1 in “Key Resources”).

The ten scenarios were objects for negotiation and change by educational researchers, teachers and technology experts (which focused more on the intended use of technology) during five stages of cyclical design.

### **Scenario profiles: Tools to structure reflection on the reliability of the scenarios**

The second set of design specifications were what we called 'scenario profiles', a kind of a meta-data summative description. It was addressing researchers and technology experts and was meant to function as reflection tool for the scenarios. The profiles were meant to offer a summative portrait of each of the scenarios, to highlight the theoretical grounding that delineated why each respective scenario was suitable for supporting L2L2 with the META-FORA Platform and to render reliability to the scenario itself. Scenario Profiles facilitated the screening implemented in Stage 1 of the Design and Development Phase. Specifically, the design specifications for scenario profiles involved a) the theoretical assumptions underlying the design decisions for the scenario with respect to L2L2 and meaning generation b) the crafting of connections between scenario activities not only with different aspects of learning (i.e. collaboration, construction of public artifacts, scientific inquiry etc.) but also with specific L2L2 and domain learning objectives and c) the envisaged use of technology according to the theoretical assumptions of the scenario. (See Deliverable 3.1 - Key Resources). Scenario profiles were used as tools for expression of meaning and negotiation between the educational researchers (CSCL community and exploratory-constructionist learning community) but also as tools for grounding negotiations with the technological experts. Scenario profiles and especially the underlying theory, was expected to be refined after the Evaluation Phase.

### **Implementation protocols as input to the implementation of the intervention**

The third set of design specifications was the implementation protocols. These explained the role of the researchers in the intervention and offered detailed accounts of the implementation context. For each scenario we produced one implementation protocol functioning as input to the process of the pedagogical intervention describing in essence the conditions under which the pedagogical intervention could be successfully implemented.

In brief the input described in the implementation protocols related implementation to the characteristics of the educational system, curriculum of the subject matter and the school. This structuring was designed to capture context differences given that interventions took place in different countries and schools. Specifically three interventions took place in Greece, three in United Kingdom, three in Israel, and one in Spain. Implementation protocols facilitated communication with schools and with technology experts informing the latter about the uses of technology in different contexts.

#### 4. The META-FORA Platform: Description of the technology

In this section offer a short description of the technology used in order to better illustrate the orientation of our research. The META-FORA Platform integrates two different types of tools a) (CSCL)-type tools which bring into the foreground aspects of collaborative work and more specifically planning (Planning tool- Wegerif et al 2012) and discussion (Learning to Argue: Generalized Support Across Domains Acronym: LASAD (Dragon, Gutierrez-Santos, Mavrikis, & McLaren, 2011)) b) Exploratory Learning Environments -microworlds (for a definition see Kynigos, 2007)- which support students to explore concepts from the learning domains of mathematics, the sciences and environmental education.

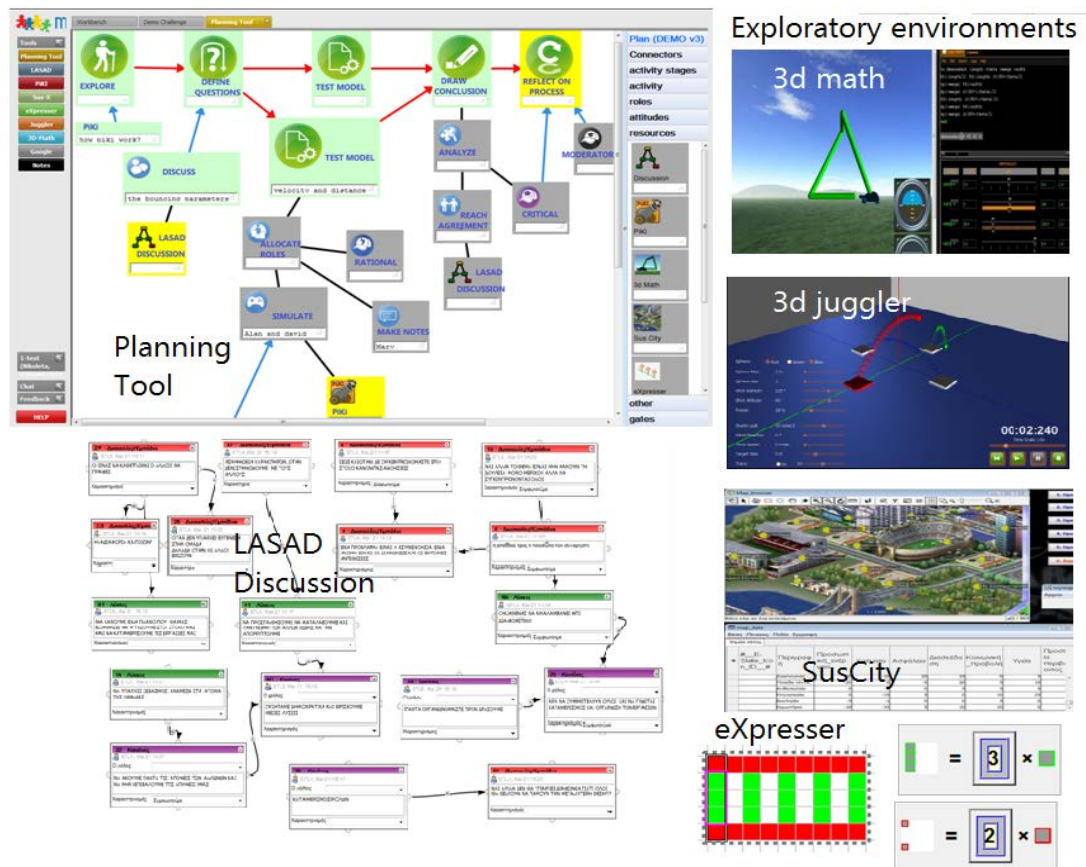


Figure 3: The META-FORA platform tools

The META-FORA Platform is not just a toolbox aggregating these different tools but offers functionalities that support communication between them. These functionalities allow students to attach in their plans specific instances of their experimentation with the microworlds or



specific instances from their discussion. Similarly, in LASAD students can transfer and integrate in their discussion instances of their experimentation with the microworlds. In the discussion space collaborators can open, explore and experiment with the specific instance and then return to the discussion if necessary (Mavrikis, Kahn, & Dragon, 2012).

The META-FORA platform was under development during the design of the pedagogical intervention, the micro-evaluations of which offered feedback to the system design. The focus however, of the research reported here is mainly on the pedagogical intervention that aimed at infusing the system in the classroom in order to support L2L2.

## **5. Design - Development phase**

The development phase involved consecutive refinements of the design of the main intervention in stage six, which aimed at raising students' awareness on how they can apply L2L2 in mathematics, science and environmental education with the use of the META-FORA Platform. The design built on previous work of the research groups with collaborating schools in the field of infusing ICT in the classroom. This means that issues related to the ecology of schools and of the educational system in each country were already addressed allowing the design effort to focus on the pedagogical exploitation of the META-FORA Platform. The grounding of the intervention on theory is described in detail next.

### **Stage 1: Grounding the prototype on theory and previous work**

Based on the design specifications created during the conceptualization phase the researchers of the four research groups produced ten scenarios to support L2L2 and meaning generation in the fields of Mathematics, the Sciences and Environmental Education with the use of the Metafora Platform (See Table 1 for a list of the scenarios produced and D.3.1 in Key Resources for the scenarios developed). The scenario ideas developed by researchers had the following characteristics a) they introduced complex problems b) they required collaborative work to be completed and c) they interweaved the concepts under investigation with powerful ideas and meaningful constructions for the students. This was the only stage with no interaction with teachers and students because the focus was on producing new teaching material that combined meaning generation with L2L2 based on theory and the affordances of the tools. The list of the scenarios produced is presented next, along with the main concepts and some keywords suggesting the theoretical grounding of each scenario. To further illustrate how theory was used as a basis for designing the scenario we will briefly refer here to one example: based on theory about game design as learning activity which involves, planning, communication and deep domain knowledge, a group of researchers proposed a scenario where students used the META-FORA Platform to plan and design their own game in the context of which they discussed and negotiated concepts related to sustainability (see Key Resources, D.3.1 "From PEfectVille to MySusCity").

Table 1: The first version of the educational scenarios

Scenario title	Author	META-FORA tools	Focus	Theoretical Assumptions: Keywords
Twisted Rectangle	ETL	3d Math, LASAD, Planning tool	Maths: geometrical properties of 3d figures, spatial thinking	Half baked microworlds Boundary objects
Constructing patterns with eXpresser	LKL	eXpresser, LASAD, Planning tool	Maths: Algebraic Generalisation (justification, equivalence of algebraic expressions)	Generalization based on the structure of a pattern and on relating every algebraic expression to the corresponding part of the pattern-model-construction collaboration around constructions
3d Juggler	ETL	Physt 3d, LASAD, Planning tool	Physics	Half baked microworld Inquiry learning and modeling Collaboration around constructions which function as public entities Boundary objects
The Gardener	HUJI	eXpresser, LASAD, Planning tool	Maths	Authentic problem solving activity and the role of multiple solutions
Describing motion with juggler	HUJI	Physt 3d, LASAD, Planning tool	Physics	Kinematics in the in the realm of "stroboscopic" pictures (a-la Edgerton) of ballistic motion
From PerfectVille to MySusCity	ETL	SusCity, LASAD, Planning tool	Environmental education: sustainability and game design	Game design Collaboration around constructions
Teaching the distributive Law	HUJI	eXpresser, LASAD, Planning tool	Maths	Student engagement in a teaching task Representations of distributive law
Eco-City	UnEXE	SusCity, LASAD, Planning tool	Science Education	think globally, act locally meeting of different perspectives moving students out of their comfort zone
Prevent summer flooding	UnEXE	SusCity, LASAD, Planning tool	Science Education	Collaborative game design Opening up of dialogic spaces
Design a scientific action to prevent water pollution	UnEXE	SusCity, LASAD, Planning tool	Science Education	Exploration of an extended range of concepts Scientific thinking skills

The research question for this stage of design was the following:

*What is the relevancy of the educational scenarios to a) meaning generation in the different scientific fields involved and b) L2L2?*

The Coordinating Research Group (Educational Technology Lab, University of Athens, hereafter “ETL”) performed a screening of the produced documents to verify that all the design specifications defined for the scenarios, the scenario profiles and the implementation protocols were met. Furthermore the aim of the screening was to verify that all pedagogical interventions introduced learning activities which according to theory, were challenging for the students and had characteristics that required collaborative work, and/or self regulation.

The screening collected and identified combinations of three theoretical trends in the interventions designed: a) those that focused on computer mediated meaning generation b) those that emphasized dialogue and collaboration and c) those that focused on self-regulation and meta-cognition (See Key Resources D.3.1). Specifically the theoretical frameworks (See Key Resources D.3.1 for the references associated with the list below) drew from:

- inquiry based learning;
- constructionist learning;
- collaboration around constructions and distributed constructionism ;
- game design as learning activity ;
- modeling in the sciences;
- mathematical generalizations;
- self regulation strategies in problem solving in mathematics;
- self regulation as meta-cognitive skill and
- dialogic space.

The first version of the prototype was produced by the research group quite early in the project (month six) which means that it was fully developed with respect to issues that built on previous work of the research groups (i.e. meaning generation, collaborative learning, infusion of technology in real classroom settings etc.) but it needed development with respect to supporting L2L2 and integrating the use of the META-FORA Platform. Furthermore this prototype was designed upon the general requirement that the challenges should call for planning of collaborative work but without consideration of the L2L2 related functionalities of the META-FORA Platform such as the planning tool and its vocabulary (a list of keywords addressing the main stages of inquiry based learning like: Build Hypothesis, Explore, Brainstorm etc. (see Figure 3)) because they were still under development (requirements specification phase). The scenarios were next distributed among the four research groups for cross evaluation and were presented and discussed in two reflective research meetings. The work that followed in the next stages aimed at re-conceptualizing the initial scenario ideas so as to trigger L2L2 with the use of the META-FORA Platform.

### **Stage 2: Focusing on planning and on the functionalities of technology**

During the second stage, emphasis was placed on planning as a facet of L2L2 which became the filter through which the different scenarios were revised. The research question for this stage was: *What is the consistency of the scenarios with the task of planning as a L2L2 activity.*

This research question guided the design of a micro-evaluation of the scenarios by teachers and researchers (described in this section). Consistency of the scenarios with the task of planning was interpreted as follows: a) that planning should not be just an add-on in the scenario but a necessary part for the completion of the task (as in robberies depicted in the movies where success depends on crafting a detailed plan and having all the participants to follow it), b) that the use of the planning tool could facilitate group-work on the specific task.

With these two filters in mind we asked the participants of this micro evaluation -researchers and teachers-: to reflect on the scenarios by trying to respond to the following questions.

- *Is planning necessary for the scenario?*
- *Are the tasks included in the scenario appropriate for planning?*
- *Is the vocabulary of the planning tool appropriate for planning the learning and collaborative activities foreseen for the specific scenario?*

The reflection process took place in what we called “Design Workshops” and involved enactment of the scenarios where participants adopted the role of the student and engaged in the process of using the vocabulary of the visual language to plan the tasks described in version 1 of the prototype. At this stage the planning tool wasn't implemented yet but there was available a first version of the vocabulary of the planning tool which focused mainly on the describing elements of the process of inquiry based learning and not elements related to collaboration such as roles and attitudes. Each research group organized one workshop with the exception of the University of Exeter (hereafter UNEXE) who organized two (one in UK and one in Spain).

The number of participants in each workshop varied from five to eleven. They lasted from four to six hours and they were structured as follows: the vocabulary of the planning tool was presented and explained to the participants. Then they were asked to use the vocabulary in order to make a plan of their actions in order to perform the task described in the scenario (i.e. to construct a game for a sustainable city, or to construct a 3d juggler game or to make the shape of a twisted rectangle to close etc.). Participants worked in groups of two or three. The designers (the researchers who designed the scenarios during stage 1) worked on their own scenarios in collaboration with other researchers and / or teachers. Each workshop closed with a reflective discussion where each group presented their comments on the scenario they worked on focusing on the three reflective questions regarding planning and the vocabulary of the planning tool.

### ***Reflection and remarks***

The main remarks regarding the activity of planning were mainly related to the affordances of microworlds and to their use as expressive media. Specifically, the five evaluation groups reported that planning did not occur naturally as an activity before the task rather it functioned well as a reflection tool after performing the task. This was related to the following issues a) that meaning making is generated with the microworld and thus it evolves along with the interaction with the microworld b) that the state of the microworld changes constantly depending on the user's actions. Some of the evaluation groups mentioned that they could make a general plan before starting the task and then they could work on the details of the plan as they were also working with the microworld. These two observations triggered discussions between the researchers on the role of planning with exploratory environments in the context of constructionist activities an extract from which is presented below.

“We consider construction an emergent activity as opposed to activities that can be performed based on a pre-defined step by step plan. That is students are not expected to have a clear idea of the steps they are going to follow when engaged in constructionist activities. Instead they progressively generate ideas about what to do next depending on their actions on the microworld and on the feedback generated”. (Extract from an email discussion on the scenario “From PerfectVille to my SusCity”).

These discussions helped the group to expand the theoretical background of the scenarios with the concept of emergent planning aiming to capture the idea that plans presuppose the changing circumstances of situated actions (Suchman, 2007): *“It is frequently only on acting in a present situation that its possibilities become clear, and we often do not know ahead of time, or at least not with any specificity, what future state we desire to bring about.”* (ibid, pp.70) Exactly this is a situation often encountered in constructionist activity where learners start from what they know and proceed in constructing their knowledge through interaction and interpretation of the feedback generated by the microworld. The point is not to say that planning in constructionist activity is emergent exclusively. On the contrary, the idea is that in constructionist learning planning is manifested in two forms: one as a phase that precedes the activity and the other as a facet that emerges along with the activity (Planning **as a phase** and planning **as a facet** of the activity was asserted in a virtual “ped meeting” by Noss head of the London Knowledge Lab (LKL) one of the research groups participating in the project).

The idea of planning as a facet of the activity with the microworlds shaped our experimentation with students during the next stage of Design-development phase.

### **Stage 3: Planning as phase and as a facet of student activity**

The micro evaluation implemented in this stage of our work focused on planning as a phase and as a facet of L2L2 activity with the META-FORA Platform. We used the terms global and local plans to describe planning as a phase and planning as a facet of the activity respectively. This idea was tried with only one scenario (3d juggler) which was refined to integrate in its tasks global and local plans and it was used by two groups of students in Lab conditions. Implementation focused on only one scenario this time because the aim was to use it as pilot in the sense that we would refine the other scenarios if the ideas of local and global plans would work with one scenario.

Thus, the research questions formulated were the following:

- *What is the consistency of local and global plans as students’ L2L2 activity with the META-FORA Platform?*
- *Is planning as phase and as a facet of students’ L2L2 activity expected to be usable in a classroom which uses the META-FORA Platform?*

The above research questions were addressed in a micro evaluation of the second version of the prototype by a group of students. The micro evaluation took place in ETL in Athens. Four fourteen year old students (8<sup>th</sup> grade) worked in groups of two for four hours. The students’ teacher was present in the Lab and two Researchers from ETL. The task and the tools were presented to the students by one of the researchers. We used what we called compensating technologies because the planning tool wasn’t yet implemented. Specifically we used the FreeStyler which allowed us to integrate the refined vocabulary of the planning tool translated in Greek.

Students were presented with three videos with real jugglers performing. Next they were asked to draw with pen and paper a juggler game. After that they were asked to use FreeStyler to construct a global plan depicting the steps of game design. Then, they were asked to explore and change the juggler microworld in order to make their own game. During this phase and in parallel to microworld use, students were asked to use FreeStyler again to make their local plans i.e. perform an action on the microworld observe what happens depict the situation and plan the next step. Researchers kept field notes of student work. Students’ discourse in relation to their interactions with the tool was recorded with screen capturing software. A summary of the

analysis of student work (plans and games), students' discussions and researchers' notes is presented next.

### Reflection and remarks

The main conclusions from the micro evaluation can be summarized in the following points:

- Global plans provided a general overview of the activity.
- Global plans left out an interesting and rather important activity with the microworld (see Figure 4 where the local plan corresponds to the two actions of the global plan situated in the circle).

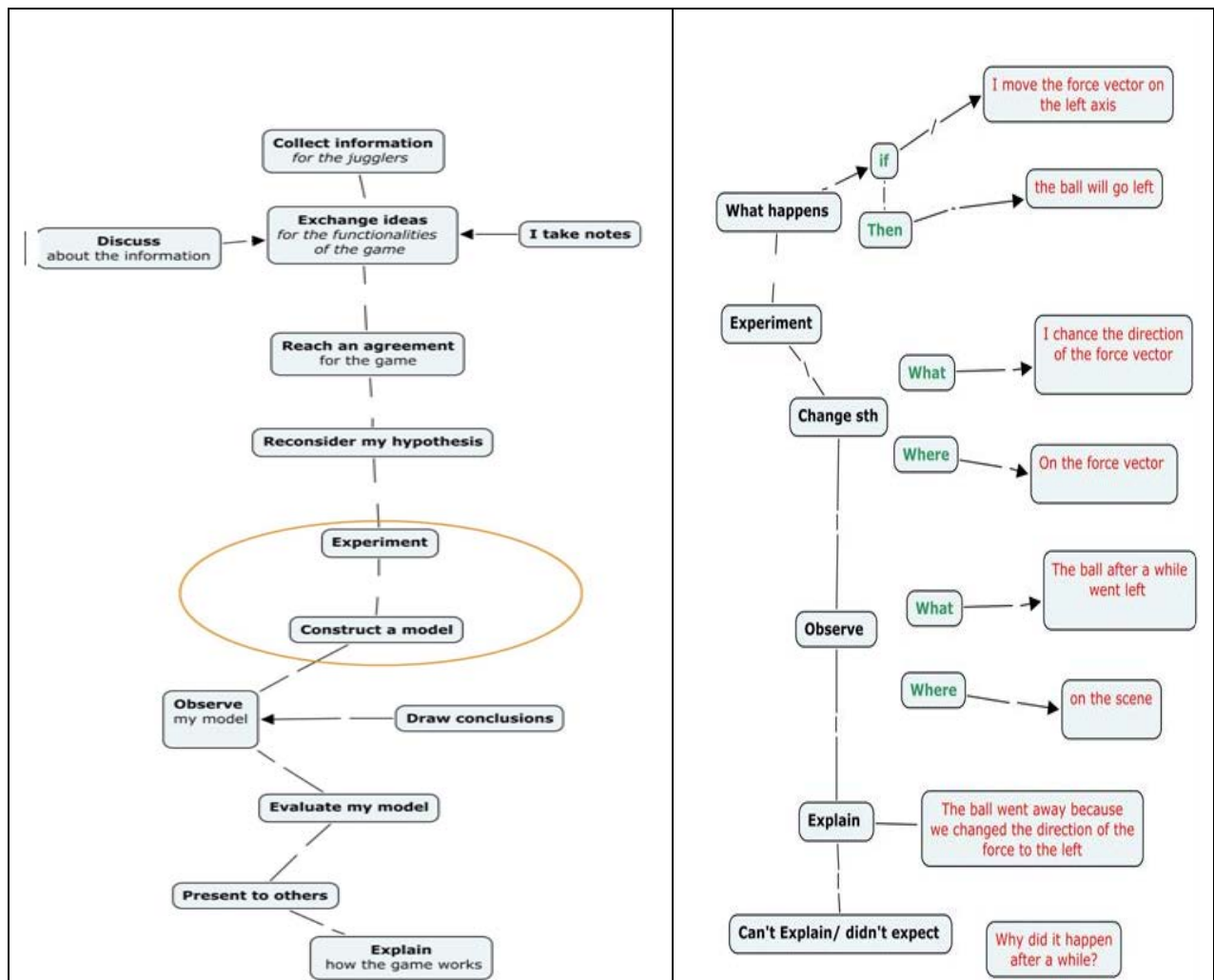


Figure 4: Students' global (left) and local plan (right) on juggler scenario

- The construction of a local plan helped students to
  - focus on what they did on the microworld,
  - keep a track of their action,
  - articulate their observations,
  - structure their experimentation around a stated hypothesis
  - to pay attention on what constituted a non expected behavior in cases where the hypothesis wasn't verified.

- Local plans were constructed under the pressure of the researcher who prompted students to include in the local plan every step they were going to take. This seemed unnatural to the experimental activity and to the idea of reciprocal shaping of meaning with the microworlds, because students wanted to continue experimenting before being able to articulate why they were doing something or what it would happen in the microworld as a result of their actions.

The above observations helped us to reflect on the necessity and the role of local plans in the scenarios designed for L2L2 with the META-FORA Platform. Specifically the scenarios were refined so that local plans were integrated in a context where their construction would be meaningful and necessary for the task and not pushed by the researcher or the teacher.

#### **Stage 4: Experimenting with the first prototype**

Our work in this phase focused on the integration in the scenarios of the first version of the META-FORA Platform. This version included all three different types of tools described earlier. We implemented a micro evaluation with students for one microworld per research group (i.e. four micro evaluations in total). The micro evaluations lasted from 3 to 4 hours, they took place in Lab settings and aimed at evaluating a) the consistency of the scenarios from the point of view of the use of the META-FORA Platform b) the expected practicality of the META-FORA Platform.

The results of this micro evaluation were the following:

- L2L2 was restricted mainly to problem solving.
- LASAD was used mainly as a chat.

Reflection guided a) the design of the planning tool which was enriched with vocabulary involving roles and attitudes in order to support awareness on collaboration and b) refinement of the topics of discussions foreseen for LASAD.

#### **Stage 5: Pilot studies: Involving teachers and students**

This was the final stage of the Design and development phase which resulted in a set of guidelines for designing a pedagogical intervention where students engage in L2L2 mathematics and sciences with the META-FORA Platform.

The research questions formulated for this stage were the following.

- *What is the consistency of the scenarios with meaning generation in the context of L2L2 when supported by the META-FORA Platform?*
- *Are the scenarios expected to be usable by teachers and students?*
- *Are the scenarios expected to be effective for students to generate meanings in Maths, Newtonian Physics and sustainability in the context of L2L2?*

10 pilot studies were implemented -one for each scenario (See table 1 for a list of the scenarios and del. D.3.1 for a detailed description- Key Resources)-with groups of 3-4 students for 2-4 hours. In six studies, the scenario was taught by the teacher after a walkthrough over the version 4 of the scenario in a face to face meeting with the researchers. In four studies the researchers undertook the role of the teachers.

In order to be able to evaluate our scenarios with respect to their consistency, their expected relevance and their expected effectiveness we designed a set of equivalent activities that

allowed us to evaluate the main idea of the scenario in the timeframe of the 2-4 hours instead of the 20 hours for which the initial scenario is designed. Equivalent activities should a) consist of a simpler task which corresponds to the main objectives of the scenario b) involve the use of all three types of META-FORA Tools and c) preserve the social orchestration of the scenario. For all pilot studies we collected qualitative data and specifically a) researchers' field notes, b) sound recordings of students' talk, c) recordings of student interactions with the META-FORA Platform with screen capturing software d) chat messages exchanged between the groups of students via the META-FORA Platform. Students' talk was transcribed and enriched with researchers' field notes and screen shots of critical interactions with the technology.

The data collected focused on students' interactions with the tool, the other students and the teachers. Analysis of the data offered insights about the manifestation of L2L2 in the different scenarios, the use of the META-FORA Platform and the meanings generated, and suggestions for the refinement of the scenarios.

### ***Reflection and final remarks***

After the analysis of the data from the pilot studies a refined version of the scenarios was produced. Refinements involved mainly (a more detailed overview is offered in D.3.2; see Key Sources):

- Changes in the timing of activities (i.e. giving more time to planning).
- Introduction of preliminary activities for familiarization with the planning tool.
- Refinement of the topics of discussion in LASAD.
- Changes in the social orchestration.
- Changes in the use of the META-FORA Platform: a shift from linear and sequential use (i.e. first the planning tool then the microworld, then LASAD) to more complex patterns described in the design principles.

Furthermore and with respect to the effectiveness of the intervention the use of the planning tool in the context of the pilot studies seemed to have raised students' awareness on aspects of L2L2 such as negotiation of disagreement, distributed leadership, awareness of group round rules etc. (for an analysis of the results related to L2L2 see Deliverable D.2.2, D.2.3 and D.3.2).

The results of the pilot studies were used for reflection between the pedagogical and the technical partners of the project in a face to face project meeting. Reflective discussion triggered the formulation of a set of design principles for educational activities that aim to support meaning generation in the context of L2L2 with the use of the META-FORA Platform (presented in detail next)

## **6. Yield of the project: Boundary objects and design principles**

We consider the impact of our work two-fold: the first aspect involves EDR per se and the other involves the output of the intervention. With respect to EDR our contribution is the three boundary objects (i.e. scenarios, scenario profiles and implementation protocols) we constructed to facilitate Design Research in the field of technology Enhanced Learning where cross-section work is required. After the completion of our Research we will reflect on the three boundary objects having in mind the following questions: what is a good improvable boundary object and what kind of design principles can emerge for such tools so that they support EDR in diverse communities?



With respect to the output of the intervention our contribution is a set of design principles. The idea to identify a set of design principles was triggered mainly by discussions that involved data which showed that students found it difficult to plan or focused mainly on the task and did not attempt to regulate their collaboration. The discussion on these difficulties was related to the characteristics of the scenarios we designed and became the basis upon which we formulated design principles for scenarios supporting meaning generation in the context L2L2 with the META-FORA Platform. Specifically the design principles we will present next address the following aspects of the scenario a) the focus of the scenario b) the use of the tool c) classroom orchestration and activities triggering L2L2. Each set of design principles is more like an abstraction from best practices offering successful alternatives rather than a set of rules that all have to be followed.

### Design principles about the focus of the educational scenarios

The question addressing this dimension was the following: what are the characteristics of a scenario designed to foster L2L2 mathematics and sciences with the META-FORA Platform? Responses to this question came from process oriented theories and domain specific learning and were triggered by the empirical data especially during the reflection on the data collected in stage 2 and stage 5 of the Design and Development phase. In the table below we present the main theoretical approaches used and derived implications for design (An analysis of the theoretical approaches is offered on the Addendum of D.3.2- Key Resources).

Table 2: Design principles based on theoretical approaches and triggered by our work on empirical data

<b>Design guidelines on the focus of scenarios:</b> <i>What kinds of scenarios are appropriate for Meaning generation in the context of L2L2?</i>		<b>Design - Development Phase</b>
<b>Theoretical approaches</b>	<b>Design Guidelines</b>	
Challenge based learning (Wegerif et al 2012)	Introduce problems <ul style="list-style-type: none"> <li>• Open ended and messy</li> <li>• Connected to real life</li> <li>• Related to the ideas and interests of children (Scardamalia 2000)</li> </ul>	Stage 2, Stage 5
Conceptual fields (Vergnaud, 1991) and constructionist learning	Introduce Scientific concepts <ul style="list-style-type: none"> <li>• Situated in a network of related concepts</li> <li>• Relevant to one or more problems</li> </ul>	Stage 2, Stage 5
Collective engagement with mathematical meaning generation (Stahl et al., 2010)	Introduce fallible mathematical ideas to foster mathematical practices related to discussion, negotiation and mathematical experience	Stage 2, Stage 5
Action competence (Jensen & Schnack, 1997)	Introduce complex problems Focus on undertaking action for environmental problems	Stage 2, Stage 5

### Design principles on classroom orchestration

The second set of design principles involves data-grounded observations for possible classroom orchestrations that can trigger L2L2 in the context of specific activity types. Next we present a table with the forms of social orchestration and the activities in the context of which this social orchestration is observed to trigger L2L2.

Table 3: Social orchestration and related activities

<b>Design principles on classroom orchestration</b> <i>Organizing group work for specific kinds of activities</i>		<b>Design and Development Phase</b>
<b>Social Orchestration</b>	<b>Activities</b>	
Combine inter with intra group collaboration	<ul style="list-style-type: none"> <li>• Comparing solutions</li> <li>• Finding solutions to the same problem</li> <li>• Collaborating towards the same construction (i.e. two groups to construct one game)</li> <li>• Asking and providing help</li> </ul>	Stage 5 ETL, LKL
Splitting and converging in the group	<p>Split to analyze a problem, record opinions, brainstorm etc</p> <p>Converge to select the best elements for the analysis from all members of the group</p>	Stage 2 (Hebrew University of Jerusalem - HUJI)

### Design principles on Tool Use

The last set of design principles involves different configurations - with respect to the sequence - in the use of the three types of tools of the META-FORA Platform i.e. the Planning Tool (PT), the microworld (mwd) and LASAD. Again each pattern of use is presented in relation to the activities that can be linked to.

Table 4: Patterns of tool use and related activities

<b>Design Principles on Tool Use</b> <i>How to use the Metafora Platform and for what?</i>		<b>Design and Development Phase</b>
<b>Use of the META-FORA Platform</b>	<b>Activities</b>	
Mwd-LASAD-PT -mwd	Use microworld to familiarize with the parameters of the task, discuss about the problem (in LASAD), plan and then work on the microworld according to the plan	Stage 5 Data from HUJI and ETL
Mwd-PT-mwd & LASAD	Use microworld to familiarize with the task, enrich and refine a ready-made plan, collaborate and discuss in LASAD with another group for co-construction on the microworld	Stage 5 Data from HUJI and ETL
PT-mwd-LASAD-PT	Revise and follow a ready-made plan, work on the microworld according to the plan & refine and change the plan during work with the microworld, compare solutions in LASAD, reflect with the planning tool	Stage 5 Data from LKL
LASAD-PT-mwd	Elaborate on aspects of the problem discussing in LASAD and using elements of the planning tool for the discussion (i.e attitudes), then plan and then use the microworld	Stage 5 Data from UNEXE

The above design principles will be refined after the completion of the main studies which is now in progress. We plan to extend them including the teachers' role and hints on students' difficulties and suggestions for overcoming them based on the data collected during the main study. These design principles will be used for the final refinement of the scenarios.

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### Key source

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Deliverables Available in [http://www.metafora-project.org/index.php?option=com\\_content&view=article&id=33&Itemid=50](http://www.metafora-project.org/index.php?option=com_content&view=article&id=33&Itemid=50) Last Access Sept. 26, 2012.

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## Using Design Research to Develop Teacher Support Materials in order to Facilitate the Successful Implementation of a New Science Curriculum in Post-apartheid Namibia

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# 19. Using design research to develop teacher support materials in order to facilitate the successful implementation of a new science curriculum in post-apartheid Namibia

Wout Ottevanger

## Abstract

*After independence from South Africa in the early 1990s a new science curriculum was implemented. A design research approach was used to develop teacher support materials in a cyclic approach of design and formative evaluation. An analysis of the context of science education in Namibia indicated numerous problem areas, among others limited teacher qualifications and only few schools with well-developed infrastructure. The design study used a three-tier structure of front-end analysis, development of prototypes and a formative evaluation of successive prototypes using the quality criteria for curricular products: relevance, consistency, practicality and effectiveness. The study has resulted in much better understanding of the local circumstances in which the new science curriculum was to be implemented, support materials which were practical for teachers to use in the preparation and execution of lessons in the class. These materials also proved to be effective assisting teachers to understand the concept of learner-centred education and how to translate this to their practical situations mostly in schools with sub-optimal infrastructures. The study has resulted in a set of design specifications for teacher support materials, in Namibia and similar settings in the (Southern) African subcontinent. For many of the teachers involved in the study it has also provided a professional learning trajectory, which is seen as important in Namibia at its post-independence period in the 1990s.*

## 1. Introduction to the problem

At independence, Namibia inherited from its colonial power a society and education system segregated along ethnic lines. A total of 11 separate educational authorities had been established, leading to duplication of activities and wasted resources. After independence, a major restructuring exercise resulted in the establishment of one Ministry of Education and Culture (Angula & Grant Lewis, 1997).

The disparity between the different population groups in Namibia prior to independence is well documented (Angula & Grant Lewis, 1997; Cohen, 1994). After independence in 1990, the Ministry of Education and Culture (MEC) introduced a massive reform programme to address the problems caused by the pre-independence education system. Not surprisingly, in the years immediately after independence, problems in the system remained. The teaching force in general - but especially for the sciences and mathematics at secondary level - was largely unqualified (Cohen, 1994). With increased access as one of the major goals of educational reform (MEC, 1993), the system expanded rapidly. The increase in the number of students caused a shortage of qualified teachers, which was often remedied temporarily by employing unqualified teachers and students who had just finished senior secondary school.

The cornerstone of the new education system was a major curriculum reform in both primary and secondary education. The Ministry of Education and Culture developed and introduced the new curriculum over a very short time-span (MEC, 1992).

Teachers had warmly welcomed the curriculum reform introduced immediately after independence, as these were seen as a much-desired break with the pre-independence educational system and curriculum. However, the translation of curriculum goals and objectives into classroom activities and behaviours left much to be desired (Van den Akker, Ottevanger, & Plomp, 1994), due to the context described above. The ministry's monitoring exercises at the end of every Grade level, not surprisingly, observed very little evidence of the reform goals manifested in the classrooms (MEC, 1991, 1993).

The INSTANT Project (The In-service training and assistance for Namibian teachers, 1991-1997) was one of the several donor-funded projects assisting the Ministry of Education and Culture in Namibia in developing the science and mathematics curricula and teaching and learning materials. Teachers expressed great appreciation for the materials, but there was very little feedback on the actual use of these materials in the classroom and their contribution to the process of curriculum implementation. Early monitoring exercises carried out by the Ministry of Education and Culture (MEC, 1991; 1993) showed that teaching had not changed to a more learner-centred style, as proposed by the new curriculum. Instead, teachers continued to be dominant figures in classroom with silent students. The INSTANT Project therefore considered a more careful development process with the teacher in the classroom in mind.

Design research seemed an attractive approach for the development of prototypes of teacher support materials in the rapidly changing Namibian context, with their ambitious new educational goals, few qualified teachers, under-resourced schools and unclear implementation conditions. In addition, design research also provided opportunities for testing characteristics of such materials and generating methodological directions (Van den Akker & Plomp, 1993). Exploring the potential of educational design research in developing countries, with emphasis on Namibia, Van den Akker, Ottevanger and Plomp (1994) forwarded two additional aspects as important:

- better understanding of the local implementation conditions and problems teachers are facing, and
- increased expertise and professional growth of the various participants in the development process.

They argued that in the Namibian situation after independence from South Africa in 1990, the education system was in constant state of change. As implementation conditions were often unclear, but varied from region to region - and sometimes from school to school - the use of design research to guide the development of programmes and curriculum materials could take away some of the uncertainties of the development process.

In line with general thinking about design research (at the time often called development research (Van den Akker, 1999; Van den Akker & Plomp, 1993; Nieveen, 1997; Richey & Nelson, 1996), the study in Namibia consisted of the following stages:

- front-end analysis, including context and problem analysis, literature review, analysis of available promising similar examples, review of intentions and perceptions of Namibian curriculum developers;
- development of prototypes through a cyclic process of design and formative evaluation activities;

- evaluation of the effectiveness of the product - in particular in terms of the way it assists teachers with a more practical teaching style with active involvement of students.

During the study the following quality criteria for curricular products were used (Thijs & Van den Akker, 2009):

Relevance: There is a need for the intervention and its design is based on state-of-the art (scientific) knowledge.

Consistency: The structure of the curriculum is logical and cohesive.

Practicality: The intervention is usable in the settings for which it has been designed.

Effectiveness: Using the intervention is expected to result in desired outcomes.

Table 1 provides a summary of the study, incorporating these three stages and the quality criteria relevant for each of the stages.

Table 1: Summary of the study

Stage in the study	General description of activities carried out in this stage	Specific evaluation activities	Focus on quality aspects
Front-end analysis	<ul style="list-style-type: none"> <li>• Context analysis of education in Namibia</li> <li>• Literature study of science curriculum implementation, incl. Southern Africa region</li> <li>• Analysis of available promising examples for similar purposes</li> <li>• Analysis of local experts' views</li> <li>• Generating design specifications for materials supporting teachers with the implementation of the new science curriculum</li> </ul>		Relevance
Design and formative evaluation of prototypes	2. Design and evaluation of teacher support materials for the topic of <i>Materials</i>	2a. Expert appraisal	Consistency
		2b. Try-out 2c. User appraisal	Practicality
Evaluating effectiveness of materials	Design and evaluation of teacher support materials for the topic of <i>Materials</i>	2d. Field-test	Practicality Effectiveness

The following research question guided the study in Namibia:

*What are the characteristics of materials that adequately support teachers in the initial implementation of science curriculum innovation in Namibian classrooms?*

The INSTANT project adopted design research as part of its curriculum development activities. By doing so, it hoped to increase the efficiency of the process and to provide evidence of the quality of the resulting curriculum products.

The structure of the chapter is as follows:

In section 2, the front-end analysis of the study, the problem analysis of curriculum implementation and context analysis of curriculum reform in Southern Africa, and Namibia in particular, is described. Section 3 outlines the development of prototypes, focusing on teacher support materials for new but potentially vulnerable topics in the new science curriculum. Section 4 zooms in at the formative evaluation of prototypes, section 5 reports on the yield of the study, while the section 6 reflects on the broader benefits of design research as used in this study.

## **2. Development of conceptual framework/conceptualization of study**

After the initial contribution to the development of the new science and mathematics curriculum, work at the INSTANT project concentrated on the implementation on the new curricula in junior secondary schools (age groups 12 - 15 years). The focus on student-centred education and making use of the immediate environment at the school seemed very ambitious at the time. Certainly ambitious against the background of a system coming out of a long period of domination by the South African apartheid regime in which education for the majority black population groups had not been a priority. Few teachers of science were qualified for the work they were doing in schools. The infrastructure at schools was often not very well developed, facilities for a practical focus of science education was mostly absent.

Two other problems aggravated this situation: at independence the language of instruction had been changed from Afrikaans to English, and soon after independence corporal punishment of students - a regular component of the education system until then - had been abolished, creating uncertainty with teachers in the classroom.

From classroom observations a rather big gap between what the curriculum documents intended and what happened in the classrooms had become clear. This is rather in line with the various factors which negatively influence the implementation of learner-centred teaching and learning.

Some oft-mentioned obstacles to successful implementation are inherent in the Southern African sub-continent (notably in South Africa and Botswana): insufficient mastery of both subject content and basic teaching skills; language problems for both teachers and students; poorly resourced schools and classrooms; and a misalignment of curriculum goals and examination system (Van den Akker et al., 1994; De Feiter, Vonk, & Van den Akker, 1995). At the teacher and classroom level, studies in junior secondary schools in Botswana (Tabulawa, 1996; Prophet, 1995; Snyder & Fuller, 1990) and in South Africa (MacDonald & Rogan, 1990) show several factors that negatively influenced implementation of learner-centred teaching in the classroom. Similar problems existed in Namibia, and it was assumed that these factors were hindering the implementation of the new science curriculum in Namibia in the same way:

- the extra workload involved in implementing the new curriculum - the initial cost of the innovation is hindering a proper implementation;
- complexity of the innovation - if the complexity of the task becomes too great, it is unlikely that it will be implemented (for example, curriculum materials are often actively interpreted by science teachers, changing 'discover' to more traditional forms of pedagogy; Prophet & Rowell, 1993);
- negative views of students held by teachers - teachers perceive students as having limited ability, coming from poor and unsupportive backgrounds, and with poor attitudes towards school;
- teachers' and students' view of their own roles - teachers see themselves as 'delivering the goods' to students; students see a traditional role for themselves in the learning process, as 'receivers of knowledge';
- students' resistance to change - e.g. 'unwillingness to participate in group work, in favour of covering quickly and efficiently all the material to be tested in the recall-type of examinations' (Macdonald & Rogan, 1990, p. 123);
- authority structure in the class - i.e. teacher's or dominant students' views, observations and conclusions count most and discourage contributions from other students (for example, teachers keep their authority in the class intact by demonstrating expertise and knowledge of facts; comprehension of biological processes seems less important than knowing the proper English vocabulary for parts of plants; Prophet & Rowell, 1993);
- perceived quality of curriculum materials - materials need to be of 'good quality'; perceived 'cheapness' of materials can hinder implementation.

The project tried to get the curriculum picture clear by using the typology of curriculum representations as developed by Goodlad (1979) and Van den Akker (2003), see table 2. The typology distinguishes three levels within the curriculum: intended, implemented and attained. Authors argued that many of the curriculum innovations focus on the attained curriculum, sometimes in relation to the intended curriculum, without paying much attention to the implementation of the curriculum.

*Table 2: Forms of curriculum (Goodlad, 1979; Van den Akker, 2003)*

<b>INTENDED</b>	Ideal	Vision (rationale or basic philosophy underlying a curriculum)
	Formal/Written	Intentions as specified in curriculum documents and/or materials
<b>IMPLEMENTED</b>	Perceived	Curriculum as interpreted by its users (especially teachers)
	Operational	Actual process of teaching and learning (also: curriculum-in-action)
<b>ATTAINED</b>	Experiential	Learning experiences as perceived by learners
	Learned	Resulting learning outcomes of learners

Yet, in Namibian curriculum innovations it was - based on the annual monitoring of the ministry of education - clear that the lack of progress had to do with things going wrong at the implementation phase, or at least that was the conclusion at the time.

Curriculum development in the context of Namibia is a highly centralised activity. The syllabuses developed by the National Institute for Educational Development (NIED) are detailed and prescriptive, not only spelling out the content but also making pedagogical suggestions for

teachers in the classroom. Yet, it seemed that teachers were not always following the syllabus to the letter, for various reasons, such as lack of possibilities to do practical work, and lack of content knowledge. The three perspectives on curriculum implementation by Snyder, Bolin and Zumwalt (1992) appeared to be very useful in the Namibian context:

- *fidelity*: the curriculum is implemented in accordance with the original intentions of the developers;
- *mutual adaptation*: adaptations of the intended curriculum are made by curriculum developers and practitioners;
- *enactment*: teachers and students use curriculum materials as tools to construct their own curriculum in the classroom.

The fidelity perspective is often implied in large-scale curriculum innovations, like in the context of centralised curriculum development systems in African countries, Namibia included. Teachers are supposed to implement the curriculum in line with the developers' intentions. Mutual adaptation suggests a process of negotiation between the developers and teachers in schools. Enactment usually takes place when small groups of teachers and students set out to develop and implement their own curriculum, rather than implement an external curriculum.

Mutual adaptation has emerged as a preferred model by many because it provides opportunities for adjustments in the curriculum in view of changing needs, interests, beliefs, local circumstances and skills of participants and organisations. The mutual adaptation perspective (as well as the enactment perspective) puts the curriculum development process at the centre of the implementation efforts. Projects reviewed by Snyder, Bolin and Zumwalt (1992) and deemed to have been successfully implemented were characterised by a process of mutual adaptation. However, there are also undesirable scenarios of mutual adaptation (Clandinin & Connelly, 1992) such as non-implementation and or a situation in which crucial components of the reform are seemingly absorbed in the former curriculum without leading to any real change.

Implementation can be seen as the link between the intentions of the developers on the one hand, and the effects of the curriculum on the other. In turn, curriculum implementation is influenced by the context in which the curriculum operates in the school (policies and support) on the one hand, and the teachers on the other. The way this happens depends on teachers, how knowledgeable they are about the content and pedagogy and on factors in the context (facilities, school policies, support from outside and the like).

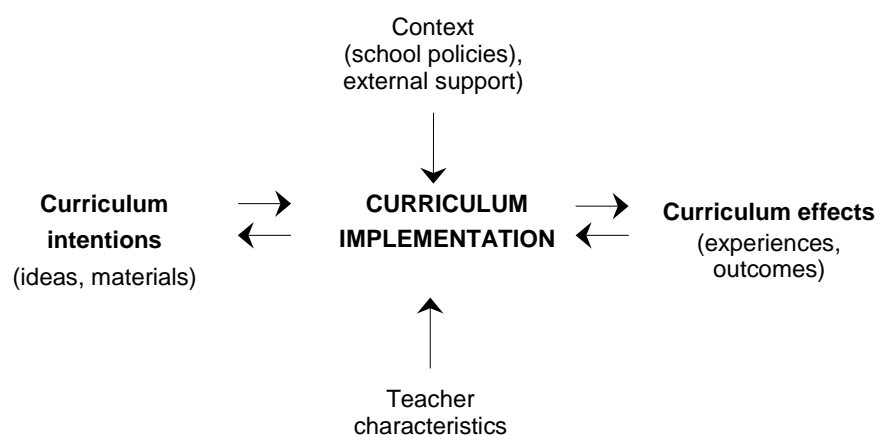


Figure 1: A framework for curriculum implementation (cf. Van den Akker, 1998)

The study used the diagram in figure 3.1 as its conceptual framework. In particular did the study set out to identify design specifications for the teacher support materials used by teachers in the implementation of the new science curriculum in junior secondary education. Van den Akker (1988) had identified design specifications for teacher materials. These were used as a starting point for the Namibian study and for the development of teacher support materials.

The study was conducted as part of the INSTANT project. The project had taken the lead in the ministry's efforts to implement the new science and mathematics curriculum. The following research question guided this part of the study:

*What are the characteristics of materials that adequately support teachers in the initial implementation of science curriculum innovation in Namibian classrooms?*

### **3. Research design**

Together with science education staff at the INSTANT Project, the researcher developed an initial prototype of the *teacher support materials* for the topic of *Materials*. The prototype closely followed the topic in the Grade 10 physical science textbook (Curry, Linow, Speelman, & Tjikua, 1994), which had become available just prior to the start of the design of the first prototype. The textbook writers were also part of the Working Group revising the science curriculum for junior secondary schools. Syllabus development and book writing developed in this way as closely related activities. Textbook authors were also involved in the in-service training for science teachers, organised by the INSTANT Project.

One of the INSTANT Project members, and editor of the Grade 10 physical science textbook, drafted the text for sections with additional background reading on subject matter notes (teacher notes). This and the feedback provided by other INSTANT staff and Working Group members, provided input and appraisal by experts.

An earlier design study on teacher support materials for the new topic on *Scientific Processes*, (Ottevanger, 2001) had established provisional design specifications suggested that development of materials should be an integral part of a more comprehensive professional development programme. During the *Materials* study, therefore, design and evaluation of teacher support materials were closely linked to the INSTANT Project's programme of workshops and other professional development activities.

The area of attention was on new topics in the new science curriculum for junior secondary education. In particular considered to be vulnerable was the new topic of *Materials*. This topic is a mix of science and of technology in which the use of a variety of materials is linked to its properties, and the properties linked to the molecular structure. Whereas this topic in many western countries this topic is often about new materials, new types of synthetic materials, in the Namibian syllabus this topic focuses on everyday materials, especially those materials used in rural areas, e.g. for building houses. Apart from the content of the topic, aspects of the reform included a focus on learner-centred teaching and learning, use of materials from the immediate environment as alternative for common laboratory equipment and consumables. Support to teachers by way of exemplary materials for use by teachers was considered to be essential in order to make the implementation of the topic successful.

The *Materials* study used the following evaluation activities (cf. Nieveen, 1997; Tessmer, 1993, Thijs & Van den Akker, 2009):

- Expert appraisal: review of prototype of a lesson series for the *materials* topic by experts, informal and on a continuous basis with the purpose to enhance consistency and to solicit ideas for activities in the classroom. This resulted in a first draft which was used for further evaluation activities.
- Try-out: two expert teachers used the first prototype materials in their classrooms, with their students focusing on the practical usability (practicality) of the materials during the lessons.
- User appraisal: teachers at workshops acquainted themselves with the lesson series on *Materials* by carrying out several of the activities described in the lessons, and provided suggestions for further development. They evaluated the practicality (level of the activities, the equipment and material requirements in view of their own classroom situations. The appraisal had a dual purpose: 1) to review practicality and to solicit further ideas for inclusion in next prototypes and 2) for teachers to acquaint themselves with the current draft, the latter as professional development in support of the implementation
- Field test: the lesson series was used by six teachers in their classrooms in two different educational regions in Namibia, with the purpose to observe practicality but also to see how teachers were using the exemplary materials, and to gauge the perceptions and experience of teachers about the lessons and the materials, as well as students' perceptions and experiences of the lessons.



## Lesson 1 *Material World*

**What does this lesson look like?**

- This first lesson introduces the topic of materials and sets up the framework for the rest of the lessons in this chapter. A class discussion will begin exploring the ideas and concepts which will be the focus of all the activities that follow:
  - the different *types* of materials;
  - the varying *uses* of these materials;
  - the specific *properties* of these materials;
  - the *structure* of different materials that give them certain properties.
- The teacher, together with the learners, will start to investigate which materials we use in our daily lives, how these are used, why particular materials are used for specific purposes, and how the molecular structure of these defines their useful properties. This investigation will center around all of the different materials used in a vehicle.

**What are you trying to achieve in this lesson?**

At the end of this lesson learners will be able to:

- identify the main types of materials we use in our lives;
- know that we use different materials for different reasons;
- understand that the particular uses of a material are determined by its properties;
- recognize that the properties of materials are based on their structures.

**Relevant pages in Grade 10 Textbook**

None, only the life experiences of yourself and your learners.

**Lesson plan and timing**

Activity	Approximate time
Start of lesson	10 minutes
Activity	20 minutes
Conclusion	5 minutes
Finishing the lesson	5 minutes
<b>Total time</b>	<b>40 minutes</b>

*[In most automobiles you can find glass, metal, ceramics (the spark plugs), rubber (the hoses), hard plastic (the battery case), soft plastic (the dash, steering wheel, etc.), fabric (the seats covers and carpet), and paper (labels).]*

- One poster for each of the guiding questions for the Materials chapter, with the keywords (material, use, properties, and structure) highlighted.
- What are the different **properties** of different materials?
- What **properties** make a particular **material** suitable for a specific **use**?
- How does the **structure** of a particular **material** give it certain **properties**?

These will be hung up around the classroom during the lesson, so have some Prestick or tape also ready.

- Divide the learners into groups of two or three.

## 1 *Execution of the lesson*

**Start of the lesson**

- Make sure that your material samples are spread out on your desk or table top before class begins, so that learners can see them as they come in the classroom.
- Show learners the samples of each type of material (glass, ceramics, metals, rubber, hard and soft plastics, wood, fabrics, paper, and concrete), and ask two questions for each material:
  - What do we use it for?
  - Why do we use it for that purpose?*[Eg. Show the class a piece of glass. Ask what do we use glass for? Why do we use glass for that?]*
- Try to get the learners to describe and explain two to three common uses of each material.
 

*[Eg. We use glass for beer bottles, because it is strong, transparent, and it is a good insulator. We use glass for windows, because it's transparent, strong, and easy to clean.]*
- Write these down on the board as they are given.
- Now outline the framework of the Materials chapter for the learners on the board:

### Materials

1. Use
2. Properties
3. Structure

- Explain that these three aspects of materials will be the focus throughout the lessons and all of the activities, for each type of material: how materials are used, why they are used for those purposes, and how their structures (how their atoms and molecules are bonded together, how their particles are arranged, what their composition is, or their textures)

## 1 *Preparation before the lesson*

- Common samples of the different materials that will be looked at throughout this chapter (glass, rubber, hard and soft plastic, metal, wood, fabric, ceramics, concrete, and paper).
- A vehicle for the activity, such as an automobile or cart. Make sure that this vehicle is close to your classroom. Put together your own list of all the different materials that make the vehicle, and where they can be found.

Materials - Page 6

Grade 10

Grade 10

Materials - Page 7

Figure 2: An example of the prototype materials produced for the topic 'Materials'

- determine the properties for which they are used.
- Prepare the learners for the following activity. Instruct them to get with their partners, and each have a notebook and pen ready.



**Materials required for the following activity:**  
A vehicle (a car or, if not available, donkey cart)

### Activity 1

Exploring the vehicle: a close look at its material parts.

- Ask the groups to each make a quick list of the materials that can be found on and in a vehicle.
- Now write down ideas from each group on the board to help guide them on their exploration. [Make sure you have your own list of all the materials that make up the vehicle.]
- Give them the following instructions:
  - Write "Materials that make a vehicle" on the top of a page.
  - Each group needs to find at least two uses of each material on or in the automobile.
  - Each use is to be written down in their notebooks with the specific reasons that the material is used for that particular object or function.
  - You have 10 minutes to do this.
- Take the groups outside to the vehicle. Open up all the doors, the boot, and the bonnet so that the learners can fully explore all the possible uses of the materials that are part of the vehicle.
- Allow the groups to investigate all the parts of the vehicle on their own, but interact with all the groups throughout the activity to keep them on task and to check their progress.
- After 20 minutes bring them back to the classroom.
- Lead a class discussion in which each group contributes some of its findings and ideas to a list that you write on the board for each type of material found in or on a vehicle:

E.g.

material	use	properties
glass	windows	hard, strong, transparent, waterproof
rubber	radiator hose	flexible, strong, insulator



One or two examples for each material will be fine for this exercise.



### Conclusions

- Review with the learners that what a material is used for is related to its particular properties. Again, refer to some of the examples they discovered during the activity.
- Ask the learners to think about how these same properties might be

determined by the structure of the specific material (which will be looked at in Lesson 4 and 5).

- Put up the three posters:
  - What are the different **properties** of different materials?
  - What **properties** make a particular **material** suitable for a specific use?
  - How does the **structure** of a particular **material** give it certain **properties**?
- Instruct the class to write these down in their notebooks. Explain that these questions will guide the rest of the investigations into the different types of materials we use in our daily lives.



### Finish of lesson

- Reorganise the classroom and assign homework.

### Homework

- Instruct the learners to find **one** example of each type of material (all ten) in or around their homes. For each of these ask them to write down the material and what its being used for in their homes on a piece of paper. This will be collected the next lesson.



Check out that cart! Many different materials can be found in a vehicle

Figure 3: Pages from prototype exemplary teacher support materials for the new topic of 'Materials' in the new science curriculum

The various evaluation activities in the study were embedded in a cyclic approach of design and formative evaluation for the development of a lesson series on the topic of *Materials*, taking place over a time span of about a year. Figure 4 below shows a graphical representation of the design of the study. The section below further elaborates the try-out, user appraisal and field test.

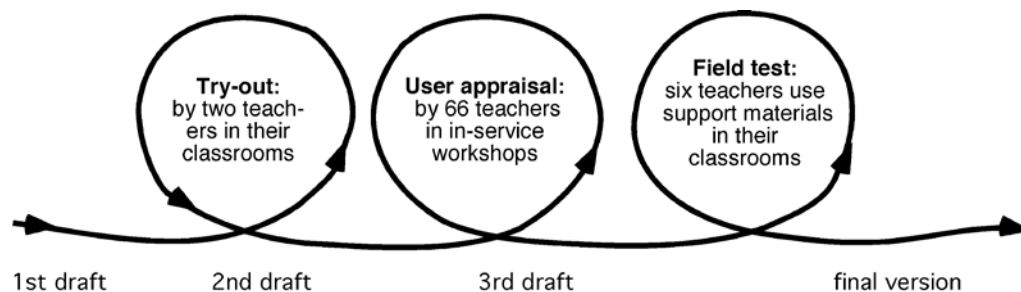


Figure 4: Research design of the materials study (Ottevanger, 2001)

### Try-out

The try-out took place with two science teachers (and their students) in almost ideal circumstances: the two teachers were among the best teachers in the country, in schools amongst the best organised and equipped in the country. The teachers and their schools were by no means representative for Namibia, but the thinking behind the choice for those two teachers was that if the teacher support materials wouldn't work in ideal circumstances, it wouldn't work anywhere. In addition, a further reason was that the thinking was that the two teachers would be able to provide suggestions on the materials from their vast experience as science teachers.

The research questions for the try-out were:

- *What are teachers' perceptions of and experiences with the proposed teacher support materials for the topic of Materials when used in the classroom, and what further suggestions for additional activities do teachers have?*
- *What are students' perceptions of the lessons?*

Two teachers and their students in two different schools were involved in the try-out of this first prototype. Both teachers were well qualified (possessing BSc degrees and teaching diplomas) and had extensive experience (over ten years) as science teachers. The two teachers were heads of their respective science departments and were teaching Grade 12 (final grade) science classes. Both teachers also held senior positions at their schools, one of them as deputy principal. They worked in 'formerly White' schools, which were well equipped and had well-organised infrastructures. One of the schools, indicated as *school 1*, was originally an Afrikaans speaking school, but with the new language policy of the Ministry of Education and Culture, had changed to English; at the other school, indicated as *school 2*, English had always been the medium of instruction.

Students in the two schools were traditionally among the best of the country, not only measured by examination results but also by results of students in science quizzes and science fair projects. Furthermore, both teachers were actively involved as regional facilitators in in-service training activities organised by the INSTANT Project.

The instruments used in the try-out included a curriculum profile (Van den Akker & Voogt, 1994) used during classroom observations, student questionnaires and student interviews. The *curriculum profile* (CP) consisted of a large number of elements, formulated as statements of 'desired behaviours' teachers would ideally exhibit during the lesson. Each lesson was divided in: start of the lesson, body of the lesson, conclusion of the lesson, and overall impression of the lesson. Statements in each lesson section were grouped in three categories: basic teaching skills, learner-centred teaching and classroom management. Each element could be scored as yes, no or not applicable. See figure 5 for an example of a part of a curriculum profile.

**Appendix 6.2 Curriculum Profile (Try-out)**

**Curriculum Profile Part 1 - Introduction to the Lesson**  
 Teacher name: School name:  
 Lesson Name: Lesson Number:

**A. Basic teaching skills**

1. Teacher introduces the lesson and series, if applicable	yes	no
2. Teacher appears organized and ready to start	yes	no
3. Teacher introduces/explains key concepts	yes	no
4. Teacher summarises introduction with preliminary conclusion	yes	no
5. Teacher illustrates lesson topic effectively	yes	no
6. Teacher achieves this by doing a short practical activity	yes	no
7. Teacher explains the use of materials/equipment	yes	no
8. Teacher appears confident in subject area	yes	no
9. Teacher appears competent in subject area	yes	no
10. Teacher makes use of classroom aids (blackboard etc)	yes	no

**B. Learner Centered Orientation**

1. Teacher relates activities to previous/future	yes	no
2. Teacher asks learners for their own ideas re: activity	yes	no
3. Teacher explains the relevance of	yes	no
4. Teacher makes correlation to textbook (where applicable)	yes	no
5. Teacher intervenes when students have problems	yes	no
6. Teacher discusses homework (where applicable)	yes	no
7. Teacher asks/answers homework questions	yes	no
8. Teacher checks homework	yes	no

**C. Classroom Management**

1. Teacher intervenes too quickly	yes	no
2. Teacher attempts to guide learners to conclusions/ideas	yes	no
3. Teacher discourages inquisitive behaviour from students	yes	no
4. Teacher ignores learners' concerns	yes	no
5. Teacher attempts to include inattentive learners	yes	no
6. Teacher poses questions but does not wait for answers	yes	no

Number of students in group today:  
 Number of students attentive:  
 Number of students in demo:  
 Number of students obviously not paying attention:

**Curriculum Profile Part 2 • Body of the Lesson**

**A. Basic teaching skills**

1. Teacher introduces the activity	yes	no
2. Teacher explains how to use materials/equipment	yes	no
3. Teacher makes sure that materials are conveniently	yes	no
4. Teacher stimulates less motivated groups	yes	no
5. Teacher's un-preparedness detracts from lesson	yes	no
6. Teacher reacts negatively to learners questions/behavior	yes	no

**B. Learner-centered orientation**

1. Teacher tells students what is expected of them	yes	no
2. Teacher allows students room to choose their own approach	yes	no
3. Teacher observes how learners choose to approach activity	yes	no
4. Teacher assists learners when necessary, but not immediately	yes	no
5. Teacher guides learners via questioning, referral, etc	yes	no
6. Teacher asks learners to report findings to class	yes	no
7. Teacher encourages learners to ask questions	yes	no
8. Teacher gives answers to learners too quickly	yes	no
9. Teacher tries to understand learner problems/questions	yes	no
10. Teacher readily grasps/handles learner problems/questions	yes	no

**C. Classroom management**

1. Teacher groups learners for activity	yes	no
2. Teacher physically mixes with students during activities	yes	no
3. Teacher ignores questions/answers from learners	yes	no
4. Teacher leaves classroom	yes	no
5. Teacher effectively handles discipline	yes	no
6. Teacher effectively handles timing	yes	no

Lesson body start time:  
 Lessonbody end time:

Figure 5: Curriculum profile (part of ~) used in the study

Several specific points, both positive and negative, arose from the try-out (cf. McKenney, 1995):

Teachers were generally well organised, well prepared and confident in the subject knowledge, lots of practical activities were going on during the lessons, teachers were clearly experienced in practical work and group work. They also encouraged questions from students and generally showed a good rapport with them. Worksheets were used for the introduction of important concepts, to guide the activity (e.g. use of the equipment), as well as for asking questions and drawing conclusions. The strong practical focus of the lessons seemed to happen at the expense of more theoretical considerations.

Time appeared to be a problem in many of the lessons. Drawing conclusions from the activities was carried out hurriedly, because of time constraints at the end of the lessons. Connecting results of practical activities to theory was also carried out in a less efficient way, possibly also to do with time running out towards end of the lesson.

Students indicated that the lessons had, in their opinion, been different from their usual lessons because of *more practical activity* and *more opportunity for group work*. They liked the lessons

because they had been able to participate in practical work, use their hands, and be outside, communicate and work together with fellow students in groups.

Specific favourite activities listed by students included:

- make bricks and test their strength;
- test various materials by hammering and burning them;
- determine insulating properties of fibres (the part where students were asked to graph results) and show their academic competence.

In addition, students felt good about being given responsibility and being taken seriously during the lessons. However, students were critical about the lack of a more solid theoretical foundation for the activities. They also indicated that they found many of the lessons too simplistic, repetition of earlier work and requested less qualitative, more accurate ways of testing.

During the execution of the lessons, as well as in informal discussions with teachers, several alternatives to suggestions in the teacher support materials were observed and discussed. As teachers allowed students a fair amount of freedom to make their own choices, students generated several good ideas on how to solve problems. This resulted in some good ideas worth incorporating in future revisions of the teacher support materials.

- Teachers felt that the first two lessons in the teacher support materials were too simplistic and too much repetition of earlier work. They indicated that they would probably skip the lessons, or perhaps combine them.
- A 'science walk' and 'exploring a car' were suggested as activities to collect different materials for classifying, testing and finding out about their uses (replacing the first two lessons in the original prototype).
- In one class, students created their own test for brick strength: a compression test, using a 'class mass' (large boy) for the test.
- Several suggestions were made for alternative materials: the use of milk cartons as moulds for brick making; Coke cans as an alternative for corrugated iron sheets; the use of animal manure in brick making.

As it seemed that the topic was quite time consuming, teachers also suggested to deal with the time constraints.

- Using afternoons to carry out the activities in the lessons. Teachers also mentioned mini-projects as possible alternatives.
- Teachers often used daily life examples to illustrate the topic of the lesson, replacing the idea of a small demonstration as suggested in some of the lessons in the teacher support materials. This alternative, born out of time constraints, was quite effective and attractive.

### **User appraisal**

This part of the study took place in rather more realistic and representative circumstances (than the try-out), in terms of teacher qualifications, school organisation and infrastructure. Teachers at two in-service workshops were asked to try out the lessons proposed in the teacher support materials and to provide feedback on the new draft of these materials. The workshops took place in two educational regions, the Katima Mulilo region in the north, and Keetmanshoop in the south of the country. The two regions are primarily the home of two of the many population groups in the country. This new draft had taken on board suggestions evolving from the try-out, including the 1) rethinking the content of the two introductory lessons which were considered too repetitive and simplistic (e.g. suggestions to include a 'science walk' instead), 2) more support for drawing conclusions from practical activities during the lessons, and 3) incorporation of

several alternatives for activities and lesson execution generated in the try-out, e.g. 'exploring a car', to make an inventory of the various materials in it, and its uses.

The research question for the user appraisal was:

*What are teachers' perceptions of the proposed teacher support materials for the topic of Materials and what further suggestions for improvement of the materials do teachers have?*

At the in-service workshops groups of teachers (n=66) were asked to provide feedback on the practicality of the teacher support materials. The feedback was organised in the form of discussion sessions and questionnaires. Feedback was analysed for similarities and differences between teachers. Conclusions from the user appraisal indicate that teachers liked the lessons in the teacher support materials for their content (*'we discovered a lot of materials which we never knew'; I liked watching the fibres under the microscope and hand lens*) as well as for the group activities in the materials which teachers also carried out at the workshops (*'group work, because everybody participated'; 'we liked that by the end of the activity a lot of people achieved something'*). Many teachers indicated that they would carry out the lessons exactly as done during the workshops. Suggested materials for the lesson would be easily available. However, there was quite some debate on carrying out activities outside the classroom. Many teachers felt that maintaining control and keeping the attention of students while being out of the classroom would be problematic.

Teachers also felt that time allocations for many of the lesson were too tight, suggestions were made for carrying out lessons in double periods, in the afternoons, in project form, whereby presentation of results and discussion could take place during the regular periods.

In addition, teachers made important contributions to the development of the materials by outlining and demonstrating local practices. In the Katima Mulilo region teachers at the workshop provided important input on the use of local materials, especially how grasses and which types of grass are used as roofing material, and how houses are built locally. During the workshop, a number of teachers collected grass samples over tea-time and gave an impromptu and impressive lecture on the different types of grass and their uses in their community. Many of these suggestions made during the user appraisal were incorporated in the new draft used in the field test which followed.

### **Field test**

A total of six teachers in six different schools took part in this field test. Three schools were located in the Katima Mulilo region, and three in the Keetmanshoop region in the country, the same regions as used in the user appraisal earlier in the study. Sampling was purposive; the two regions are in opposing climatic zones in the country (savannah and desert, respectively); schools and teachers in the two regions were also served by the INSTANT project for professional development activities, as a result of which the researchers had relatively easy access to the schools and the teachers. Three schools (two in Katima Mulilo, one in Keetmanshoop region) cater for students up to junior secondary level (Grade 10). The other three schools also include senior secondary grades (Grades 11 en 12). The number of students per school varies from 250 for one of the smaller rural junior secondary schools to 840 for the school offering all classes (Grades 8 to 12) at secondary level.

The research questions which guided the field test were the following:

- *How are lessons on the topic of Materials implemented by teachers who use the teacher support materials? Are the teacher support materials practical?*
- *What are teachers' perceptions and experience with the execution of the lessons?*
- *What are students' experiences with the lessons?*

The following instruments were used and are discussed below:

- Curriculum profile, to observe how lessons were executed in the classroom.
- Teacher logbook, to gauge problems teachers had with the lessons.
- Teacher interviews, to establish the perceptions and experiences teachers had with the lessons.
- Student questionnaire and interviews, to establish the views and experiences of students about the lessons.

A total of 32 lessons were observed, distributed fairly evenly over the six teachers involved in the evaluation, at about five lessons (a third of the total number of lessons in the lesson series) per teacher. The observations took place with two groups of three teachers, one group in the Katima Mulilo region and another in the Keetmanshoop region on either side of the country, about 1700 km apart from each other. The researcher and a research-assistant conducted the observations simultaneously, one in each region. The lessons were scored using the curriculum profile; a camera on a stand in the back of the classroom videotaped all lessons. Teacher interviews were recorded and transcribed, as were student interviews. Logbooks were also checked to see if teachers felt they had particular difficulties with some of the lessons. Results from the different instruments were triangulated.

The observers came away with a positive impression of the observed lessons. Teachers were organised and prepared for the lessons. They appeared confident and competent in the lesson content, and communicated in an open atmosphere with their students. They used classroom aids (mostly blackboard, but also posters, in two lessons the overhead projector). Teachers were able to improvise where necessary and to discuss ideas that students brought forward (Ottevanger, 2001)

Students were actively involved in many of the lessons. Lots of practical activities were conducted during the lessons. Many of these activities were introduced through discussions with the students and short demonstrations to illustrate the topic of the lesson. The discussions focused on students' ideas on the topic and activities, including how the activity was relevant in the daily lives of the students. For instance, a lesson on fibres and fabrics was preceded by an exploration of the materials used in the students' clothes: 'One student was asked to take off his (smelly) socks to see what material they were made of' (Ottevanger, 2001, p. 127).

Students were grouped for most of the activities. This was frequently done in a very practical manner with minimal disruption of the class. Students sitting close together generally put themselves together into a group. Only in some cases did teachers interfere, for instance to create a better balance in female/male composition, or to avoid that all 'the big boys' of the class would be together in one group.

Time was the biggest issue encountered in the execution of the lessons. Teachers ran out of time in many lessons. This lack of time seemed one of the main reasons for a hurried, inefficient or entirely omitted drawing of conclusions from the activities and connecting the results to the theory presented at the start of the lessons.

Compared to how science lessons are usually carried out in Namibia, it was obvious that some of the teachers in the field test used a teaching style different from their usual one. This proceeded better in some classes than in others. This was especially apparent in the beginning of classroom observations. Students in two classes were clearly not used to carrying out practical activities, and were waiting for the teacher to provide more information and show them how to do the activity. Teachers were not completely used to this new teaching approach either. In the first few lessons some of the teachers seemed to feel uncomfortable, but this got much better in the course of the lesson series. The average scores in the sections basic teaching skills, learner-centred teaching and subject matter of the curriculum profile show positive summary scores for all teachers.

The conclusion section proved to be the most challenging part of the lessons. Drawing conclusions from the activities was a part of the lesson with varying quality. Although the curriculum profile shows a reasonable number of lessons where conclusions were drawn at the end, this was often not done in a proper way. Time problems, because the activity took longer than was planned, resulted in very short periods of time left to discuss experimental results. Conclusions from the activities were often not more than a hasty summary of the experimental results. In some lessons, students were asked to complete tables of results from the experiments for homework, but it was not clear what had happened next with the results.

All six teachers felt that the workshop introducing the topic of *Materials* and the support materials had helped them to overcome their worries about the topic. '*It showed me the way I should start*' (teacher 5) and '*now that I had the teacher guide, I thought 'Materials' is something I will redo*' (teacher 6 who had already conducted the *Materials* lesson without teacher support materials). Another teacher indicated that the support materials were '*planning, that is what the teacher guide basically is, planning*' (Ottevanger, 2001).

The conclusions from the field test are that:

- Teachers make a serious effort to implement the lesson series in accordance with the ideas in the new curriculum and the teacher support materials: activity-based lessons and making use of locally available materials (e.g. for testing the strength of bricks, and the insulating properties of roofing materials, grass and corrugated iron).
- Teachers needed to get used to the new style of teaching, but seemed to 'grow into the lessons' as they series progressed. Soon teachers started to incorporate elements of earlier lessons into later lessons.
- Rounding up the activities in the lessons and drawing conclusions from them seem the most difficult part of the lesson, also because they ran out of time. Time seemed a continuous problem during the lesson series.
- The teacher support materials are *practical*, teachers feel comfortable with them, and the suggestions in them seem achievable in their context. Some teachers use the materials to the letter, others more as a broad guide, so both *fidelity* of implementation and *mutual adaptation*. Teachers see the teacher support materials as a planning tool 'planning tool.
- The teacher support materials are also *effective* in the sense that they result in well planned lesson by well-prepared teachers. Teachers used a learner-centred teaching style with lots of group work and practical activities.
- Both teachers and students indicated that the *Materials* lessons were rather different from the normal lessons, more practical, better organised and with more structure.
- Students also indicated that teachers paid more attention to them and were 'nice' to them.



## 4. Yield of the project

This section looks at the process of the design and formative evaluation in the study, including the link with professional development of teachers. The resulting design of the teacher support materials are tabled as an inventory and further elaborated for some components.

### Process specifications

The design and formative evaluation in this study followed a set-up similar to the general outlines for design processes as outlined by (e.g.) Thijs and Van den Akker (2009) and Plomp and Nieveen (2009) with similar evaluation activities.

The involvement of two very experienced teachers (at top schools) in the try-out in the very early stage of design of the prototype teacher support materials has proved to be a promising strategy. The two teachers used the first prototype of the materials in their classes and adapted them in line with their own expertise and against the background of the local conditions at the schools. It seemed curriculum enactment, rather than fidelity or mutual adaptation. Similarly, a much larger group of teachers used and appraised the teacher support materials at in-service education workshops. Follow-up visits to schools sometime after the workshops showed that teachers' sense of ownership had increased through their involvement. Ball and Cohen (1996) and Loucks-Horsley et al. (1998) have come to similar observations about involvement of teachers as an effective way to promote understanding of the changes in the curriculum and to change teacher *beliefs* about teaching and learning. The user appraisal resulted in a much better incorporation of typical local practices in the teacher support materials, as well as in a much better understanding of the problems teachers foresaw teaching the lessons.

Teachers involved in the field test initially showed fidelity towards the materials. They kept close to the lesson suggestions, but started to adapt lessons as the field test progressed. However, some teachers adapted the materials right from the beginning to suit their needs and possibilities. Teachers with the better qualifications tended to be more prepared to adapt lessons than their less qualified colleagues. In terms of the model of curriculum implementation provided by Snyder et al (1992) patterns of use of the materials involved *fidelity* and *adaptation*.

### Design principles for teacher support materials

The study in Namibia focused on the design and formative evaluation of the teacher support materials. It has resulted in design principles which seemed very similar to the design principles established earlier during the design and evaluation of materials on the topic of *Scientific Processes* (Ottevanger, 2001). On the basis of the Namibian study a number of additions were made addressing the specific Namibian conditions (list of materials requirements for the topic as a whole; exemplary worksheets in case these are not available in the student textbook; description of how the practical activities in the lessons contribute to achieving lesson aims; more support for drawing conclusions from practical activities). Table 3 shows the complete set of design principles.

Table 3: Design specifications for teacher support materials as a catalyst for the implementation of the new science curriculum in Namibia

Catalyst function	Design specifications
Support for lesson preparation	<p><i>Overview of all lessons in topic</i></p> <ul style="list-style-type: none"> <li>• introduction to the topic</li> <li>• short description of all lessons</li> <li>• list of materials and equipment required for the topic as a whole</li> </ul> <p><i>General description of lesson</i></p> <ul style="list-style-type: none"> <li>• description of what lesson will look like</li> <li>• aims of the lesson; very clear description of the purpose of the lesson, and how activities contribute to the lesson aims</li> <li>• references to resource materials and further reading; and/or inclusion of relevant pages from the textbook</li> </ul> <p><i>Lesson preparation</i></p> <ul style="list-style-type: none"> <li>• possible difficulties during the lesson</li> <li>• materials required during the lesson and possible alternatives if not available</li> </ul>
Support for subject knowledge	<p><i>Subject content</i></p> <ul style="list-style-type: none"> <li>• factual information on (difficult) concepts</li> <li>• possible student questions and answers</li> </ul>
Support for teaching methodology	<p><i>Teaching strategies</i></p> <ul style="list-style-type: none"> <li>• concrete suggestions for the role of the teacher</li> <li>• suggestions for grouping</li> <li>• suggestions on how to hand out materials</li> <li>• exemplary worksheets to guide activities</li> <li>• sequencing of activities, including starting up and finishing of the lesson and suggestions for homework</li> <li>• suggestions for questions (and possible answers) to guide drawing conclusions from practical activities and connection to theory</li> </ul>
Support for checking learning effects	<p><i>Learning effects</i></p> <ul style="list-style-type: none"> <li>• suggestions for student activities, test questions, and homework to check learning effects.</li> </ul>

The elements in the table are reflected in teacher support materials in the following manner:

- Many teachers at junior secondary level in Namibia seemed to have problems with properly visualising how a lesson would materialise, both in terms of time, equipment and materials required, and selected teaching approach. Hence, the teacher support materials provided this inside in the first of the relevant pages for this lesson, under the headings: 'What does this lesson look like?', 'Lesson plan and timing', and 'Preparation before the lesson. Results of the formative evaluation activities indicate that when teachers use the teacher support materials they are much better prepared for the lessons.

- Many teachers in Namibia are unqualified for the level they are teaching, or are teaching out of subject. As a result subject knowledge is often problematic. In the teacher support materials there is therefore a section introducing the main concepts of the topic.
- From earlier lesson observations it became clear that teachers did not have a clear view on the teaching approach and/or teaching sequence for a lesson, any lesson. The result of this was that there was often not a plan for the lesson, and no other teaching aid than a piece of chalk and a blackboard. An extensive focus on what is called 'Execution of the lesson' (divided in a start, a middle section in which activities are carried out, and a conclusion section), was therefore included in the teacher support materials. This has resulted in much better structured lessons, as shown by the results of the evaluation.
- Similarly, there is usually very little attention on different forms of grouping of students in the class. Whole class teaching was the norm. Suggestions for how to group students for a specific activity, how to hand out materials for such an activity and a worksheet for the activity written in such a way that it can also be copied on the blackboard in case there is no paper and/or copying facilities, were included in the teacher support materials. This has resulted in better organised group activities, even though some teachers continued to have problems getting away from whole class teaching.
- Checking learning results is part of the teacher support materials to facilitate testing, informally via homework exercises and via formal end-of-topic tests.

## 5. Reflection and lessons learned

### Benefits of using design research

The front-end analysis and classroom observations and discussion with teachers have provided a much better understanding of the implementation context and the problems facing the education system in general in Namibia.

The design and formative evaluation of the teacher support materials has resulted in a promising intervention and has provided guidelines for development of future activities in similar settings. Design studies in Tanzania (Tilya, 2003; Mafumiko, 2006) and Botswana (Motswiri, 2004) are examples of this.

Participants in the study, teachers, INSTANT project staff, advisory teachers in the regions, have all benefited from their involvement in the design and evaluation of the teacher support materials. This was considered to be especially useful in light of the need for building local capacity in developing countries.

Ball and Cohen (1996, p.7) who suggest that materials be developed *'to place teachers in the centre of curriculum construction and make teachers' learning central to efforts to improve education, without requiring heroic assumptions about each teacher's capacities as an original designer of curriculum'*. This Namibian study has clearly done just that.

### Role of designer, professional development facilitator and researcher

The researcher had - as a member of the INSTANT project team - several roles in this study. Apart from the role of researcher, there were also the roles of designer of the teacher support materials, and of professional development facilitator. Combining these roles was at times rewarding, but also posed problems. One such problem was the conflict of researcher versus facilitator in professional development activities. During classroom observations there was ample opportunity to provide feedback to teachers on the lessons that were observed. These

were excellent moments to support teachers in their development. However, for the purpose of the research it seemed better to just observe and see how the teachers would use the materials - by themselves - to execute the lessons. However, in a few cases the researcher assisted teachers with the preparation of the lessons, and was involved in reflecting afterwards together with teachers on some difficult parts of observed lessons. This seemed only natural at the time in view of the double role of the researcher.

The researcher was intimately involved in all aspects of the design and evaluation of the teacher support materials. There was the danger that the teachers participating in the studies would give socially desirable and overly optimistic reactions to the intervention because of the presence of the designer of the materials. Another danger was the possibility of drawing too positive interpretations of data collected from classroom observations, interviews and questionnaires. Triangulation of data sources, methods and of researchers provided measures to counter this. Research assistants, who were relative outsiders to the INSTANT Project and Namibia, were, together with the researcher, involved in classroom observations, student and teacher interviews in both sub-studies and acted as critical partners during reflection on the various research data. Their roles have proved to be very useful.

### **Key source**

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## Topic-specific Design Research with a Focus on Learning Processes: The Case of Understanding Algebraic Equivalence in Grade 8

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Credits



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# 20. Topic-specific design research with a focus on learning processes: The case of understanding algebraic equivalence in grade 8

Susanne Prediger & Larissa Zwetschler

## Abstract

*How can students acquire conceptual understanding for algebraic equivalence? What are the students' conceptions and how can they be further developed? What hinders this process, and what can facilitate it? We present a case study addressing these questions in mathematics education that is conducted within the framework of topic-specific Didactical Design Research with a focus on learning processes. The framework is briefly presented, and the topic-specificity is explained. The illustration by the case study on understanding algebraic equivalence shows how a Didactical Design Re-search project is conducted in five cycles between the four working areas specifying and structuring learning goals and contents, developing the design, conducting and analyzing design experiments in laboratory and classroom settings, and developing local theories on teaching and learning processes.*

## 1. Framework of topic-specific didactical design research with a focus on learning processes

Like other approaches to Educational Design Research (cf. Plomp & Nieveen, 2009; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006 for overviews), our framework of Didactical Design Research relies on the iterative interplay between designing teaching-learning arrangements, conducting design experiments and empirically analyzing the processes (following Cobb & Gravemeijer, 2006). It has two equally important aims, namely to generate 1. *Research results* (local theories on content specific teaching and learning processes with typical learning pathways and obstacles, and typical conditions and effects of design elements) and 2. *Design results* (evaluated teaching-learning arrangements and design principles and strategies) (see figure 1).

As we work in mathematics didactics, the problems treated are didactical and not generally educational, which means that we focus on learning specific contents and ask not only *how* to learn, but also *what* to learn and how these are intertwined (van den Heuvel-Panhuizen, 2005; see also Biehler, Scholz, Sträßler, & Winkelmann, 1994, for didactics as a research discipline). For example, if we treat the well-known problem, "How can mathematics classrooms be designed in a way that students really have the chance to understand the mathematics contents instead of simply learning calculation routines?", a major didactical question is to clarify which knowledge elements, conceptions, experiences, and skills are exactly necessary for the conceptual understanding of a specific mathematical topic.

Whereas Plomp and Nieveen (2009) emphasize the need for Educational Design Research especially for *new* educational problems, most of the practical problems that we treat are well-known and to a certain degree "solved" on a very general level.

For example, there is a certain consensus within the community of mathematics didacticians and teachers regarding design principles for the aforementioned understanding-problem: for giving students access to conceptual understanding of mathematical topics, teaching-learning arrangements should generally start from meaningful (often out-of-school) contexts, provide adequate representations, and allow students to build adequate models of the mathematical topics (Freudenthal, 1991). Notwithstanding this general “solution” (or design principle), there is a further need to clarify how these general principles can be concretely realized for specific mathematical topics, such as dealing with algebraic expressions: Which meanings (mental models) are necessary for dealing with algebraic expressions?; Which contexts and which representations can be provided to support the individual construction of meanings for this specific topic?; How do they have to be connected in the learning process for allowing understanding?; What initial conceptions do students have prior to the instruction?; How can we build on them?; What typical obstacles appear for the concrete topic?; For answering these kinds of questions, the general, topic-independent principles must be enriched by very concrete, topic-specific design research. The design research aims at finding concrete ways of realization (design results) as well as at specialized knowledge regarding typical, topic-specific learning and teaching processes (research results). Although some elements of the local theories are of course transferable to the next topic (e.g., from algebraic expressions to fractions), the topic-specific research is needed in each case and characterizes our Didactical Design Research. Figure 1 shows the four working areas that are *iteratively* connected in the design and research processes. The areas are *intertwined* in the sense that each cycle builds upon the results of the previous cycle across the different working areas. Notice that the models deliberately have no explicit starting point, since it varies from project to project. Usually, projects start from didactical problems in context, but other projects also start from theoretical concerns or empirical results (e.g., Prediger & Schnell, 2014; for an example from stochastics).

### **Content-focused**

Due to the importance of the learning content, “specifying and structuring learning goals and contents” is specified as an own working area in the FUNKEN-model for Didactical Design Research (Prediger *et al.*, 2012; FUNKEN is the interdisciplinary graduate school in which the model was developed). This comprises not only the optimal order of pre-defined topics, but also their restructuring with respect to central meanings and relations to everyday thinking, for which the mediation between students’ perspectives and scientific perspectives is a major methodological step (Prediger, 2008; Duit, Gropengießer, & Kattmann, 2005). *Process-focused*: The empirical analysis is focused on individual (and socially contextualized) learning processes as generated by the developed teaching-learning arrangements.

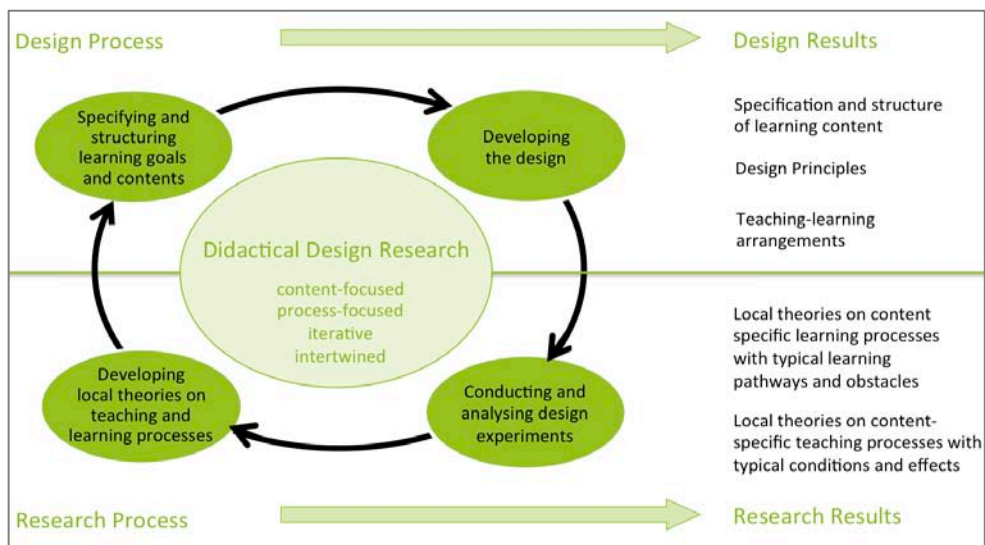


Figure 1: FUNKEN model for didactical design research (Prediger et al., 2012)

## 2. Snapshots from the concrete case “Understanding algebraic expressions”

The following case study offers concrete examples for explaining the working areas in more detail. In the next sections we present it by specifying empirical and theoretical starting points, an overview on all design experiment cycles, and then insights into the different cycles.

### Empirical and theoretical starting points

We can only sketch the theoretical background and the empirical state of research by illustrating the process of problem specification, the specification of learning content, and topic-specific research questions.

### Problem specification

Starting point for the project was a typical error while transforming algebraic expressions and the subsequent dialogue between the teacher researcher (first author) and her student Lea, 15 years old.

- 44 Lea [has written  $10n + 3 = 13n$ ]  
 45 Teacher Have a look,  $10n + 3 = 13n$ , is that really correct?  
 46 Lea Yes, why?  
 47 Teacher Just insert a number for  $n$  and test it.  
 48 Lea What do you mean by that?  
 49 Teacher Well, just take the 4 instead of  $n$  and write it down.  
 50 Lea [writes  $10 \cdot 4 + 3$ , hesitates] No, it would be times. [writes  $10 \cdot 4 + 3 = 43$ ]  
 51 Teacher And the  $13n$ ?  
 52 Lea They would be, uh, 52.  
 53 Teacher And, do you see something?  
 54 Lea No, what? [looks at the numbers, hesitates] Is it wrong, though?  
 55 Teacher The result isn't equal?  
 56 Lea No, but ... that is with 4, not with  $n$ .

(Prediger, 2009, p. 228)

Lea makes a typical error while transforming algebraic expressions that is well known from empirical investigations as syntactical error pattern “similar to similar” (Tietze, 1988). The student seems to assume that the two algebraic expressions  $10n + 3$  and  $13n$  are equivalent, since she does not realize her error when prompted to it (in line 45/46). Drawing on the theoretical distinction between syntax (routine transformation) and semantics (meanings of mathematics signs) (Malle, 1993), the teacher adopts a typical didactical strategy for dealing with syntactical errors, namely “go back to the meaning of mathematical signs” (Prediger, 2009). She hopes that Lea can identify and correct her error when she realizes that the assumed algebraic equivalence does not correspond to its meaning for concrete numbers (line 47, 49, 55). For this purpose, the teacher refers to the meaning “insertion equivalence” of algebraic equivalence (see below). However, Lea does not seem to connect the transformation equivalence of expressions (which she incorrectly applies) to the insertion equivalence, and without this conceptual understanding, she still cannot realize her error. This episode illustrates one facet of the central problem that is addressed in our design research project: *Q1. How can students acquire conceptual understanding for algebraic equivalence?*

### **Specification of learning content and topic specific research questions**

Before the “how” can be investigated, the “what” must be specified (van den Heuvel-Panhuizen, 2005): Conceptual understanding of algebraic equivalence comprises three different meanings that have to be connected to each other: Two algebraic expressions are said to be equivalent:

- (a) *description equivalence*: ..., if they describe the same phenomenon (same geometric pattern, same situation, same function, ...);
- (b) *insertion equivalence*: ..., if they have the same value for all inserted numbers;
- (c) *transformation equivalence*: ..., if they can be transformed into each other according to the transformation rules (commutativity, associativity, distributivity). (Malle, 1993, p. 46).

For the design of the teaching learning arrangement, we started with a core activity (illustrated in figure 2) that is often suggested in the literature (Wellstein, 1978; Mason, Graham, & Johnston-Wilder, 2005; Malle, 1993), namely compare expressions that describe the same geometric shapes: “While formulating and interpreting expressions in meaningful situations ... the transformation rules *result naturally*, when a situation is described in two ways” (Malle, 1993, p. 239, italics added).

However, the first design experiments showed that this activity and the individual construction of intended meanings are not as “natural” as mentioned by Malle in the quotation. Weaker student, especially, seem to be hindered by alternative conceptions of the situations. These alternative individual conceptions might be the reason why the teaching/learning arrangement does not always facilitate the intended learning outcomes.

It is our social constructivist theoretical background (Smith, di Sessa, & Rochelle, 1993; but with a focus on social constitution of meanings, cf. Ernest, 1998) that suggests investigating students’ conceptions in more depth in order to develop the teaching/learning arrangement towards a more fruitful communicative mediation between student thinking and intended meanings. So we added two further leading questions for the research project design:

- *Q2. What conceptions do students have and how can they be further refined?*
- *Q3. Which elements of the teaching learning arrangement can hinder this process, and which can facilitate it?*

### Overview on five design (experiment) cycles and different types of results

Table 1 gives a very brief overview of the complex process of the design research study with its five cycles in different stages. Although each cycle covered all four working areas (see Figure 1), they were conducted by different agents, prioritize different aims, and, therefore, had different methods and results (cf. Nieveen, 2009, p. 96). The research questions were always given by Q1-Q3, but with different priorities concerning the different specified aims.

Table 1: Five cycles of design and design experiments

<b>Preliminary Analysis 0</b>	Aim	Problem and Design Specification
Didactician as teacher/researcher (=1 <sup>st</sup> author) (2005-2009)	Methods	Analysis of typical students errors and conceptions in normal classrooms; Literature review to find theoretical conceptualization and guarantee relevance
	Results	Need for design for conceptual understanding; Specification of learning content
<b>Design Cycle 1</b>	Aim	First design and redesign of the teaching learning arrangement
Designer team (didactician, expert teacher, PhD student = 2 <sup>nd</sup> author) (Sep 10 - Jan 11)	Methods	Expert evaluation with respect to conceptual coherence, cognitive accessibility, suitability of contexts, ... by 4 experienced designers (editors of KOSIMA-project)
	Results	Redesigned teaching and learning arrangement in preliminary version for experiments (→ Prediger, Zwetschler, & Schmidt, 2011)
<b>Design Experiment Cycle 2a</b>	Aim	Experimenting with selected parts of the design (core activities) – First experiences
PhD student & didactician as designer & researcher (Jan 11 - Apr 11)	Methods	Design exp. in laboratory setting with 2 pairs of students on selected tasks (3 x 45 min.) First analysis of videos with respect to typical challenges and resources
	Results	First observation of typical challenges: Enriched specification of the learning content; Enhanced teaching and learning arrangement
<b>Design Experiment Cycle 2b</b>	Aim	Deepening the analysis on selected parts of the design (core activities)
PhD student & didactician as designer & researcher (Apr 11 - Nov 12)	Methods	Design exp. in laboratory setting with 2x2 students on selected tasks (3-4 x 60 min.) i) First analysis of videos with respect to further challenges and resources ii) Deep qualitative analysis of transcripts (of Cycles 2a and 2b) with respect to typical challenges, resources and critical moments in the processes, with Vergnaud's (1996) analytical framework
	Results	i) Sharpened research focus & complete prototype teaching learning arrangement ii) First contributions to local theory on learning and teaching algebraic equivalence (structuring of content, typical challenges, resources, first insights into learning pathways and effects of elements of the teaching arrangement) (→ Zwetschler & Prediger, 2013)

Table 1: Five cycles of design and design experiments (continued)

<b>Design Experiment Cycle 3</b> Regular teachers as testers; PhD student & didactician as designer & researcher (Sep 11 - Nov 12)	Aim	Testing the complete prototype teaching learning arrangement in regular classrooms Deepening empirical insights into learning pathways and teaching conditions
	Methods	Design exp. in field setting in 2 classes (20-32 x 45 min.); triangulated by design exp. in laboratory setting with 6 pairs of students on selected tasks (3-5 x 45 min.) i) Evaluation with respect to learning outcomes and practicality by analyzing classroom videos, teachers' diaries, students' written protocols, and tests on students' conceptions ii) Deep analysis of transcripts with respect to learning pathways, effects, conditions
	Result	i) Enhanced teaching and learning arrangement with redesign of selected tasks ii) Further contributions to the local theory on learning and teaching algebraic equivalence (especially on learning pathways) (→ PhD thesis, Zwetschler, 2013)
<b>Design Experiment Cycle 4</b> Regular teacher as tester; PhD student & didactician as designer & researcher (Dec 11 - Mar 12)	Aim	Selectively testing the new tasks in the teaching learning arrangement; first observation on the succeeding teaching learning arrangement (transition to transformation equivalence)
	Methods	Design experiments in field setting in one class (16 x 45 min.); focused by design exp. in laboratory setting with 2 x 2 students on new tasks (3 x 45 min.) Evaluation of the classroom tests and videos with respect to cognitive accessibility and success of developing conceptual understanding in the new tasks
	Results	Completely (formatively) evaluated teaching learning arrangement that facilitates the development of conceptual understanding in the intended way; insights into conditions in the teaching arrangement
<b>Design Cycle 5</b> Designer team & editors & didactical experts from publisher as designers (Jan 13 - Dec 14)	Aim	Finalizing the teaching learning arrangement for regular use
	Methods	Detailed editing with respect to theoretical and empirical results; but also linguistic issues, layout, etc.; Collecting illustrating examples and episodes for the hand book for teachers
	Results	Chapter of a textbook for students in middle schools and handbook for teachers on typical pathways, obstacles and outcomes (→ Mathewerkstatt 8, Leuders, Prediger, Hußmann, & Barzel, 2012)

Notice that a cycle was not necessarily completed before the next one started; this is especially true for the deep analysis of the Cycles 2b and 3. Furthermore, some cycles included micro-cycles, for example when an activity was slightly changed between the first and second design experiment of the same series.

In the following subsections, we will illustrate these steps by one thematic focus that played a role in all cycles, namely the challenge of generality of algebraic expressions and geometric shapes.

Although it is only one among others, this topic is now selected for illustrating typical stages and insights in the research design process. Despite the fact that the teaching learning arrangement also comprises social settings, computer sources and specific interactional arrangements, this article focuses mainly on the tasks as one design element of the comprehensive arrangement.

**Design Cycle 1: First design and redesign of the teaching learning arrangement**

Figure 2 shows two core activities in our teaching learning arrangement that were designed at the stage of Design Cycle 1.

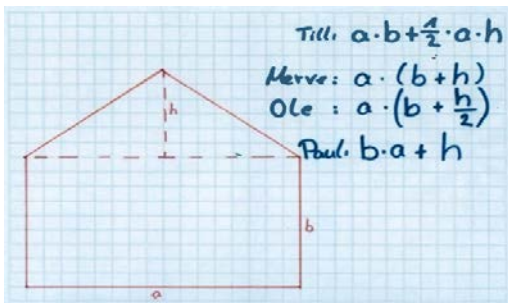
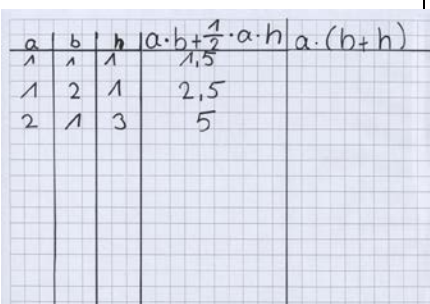
<p><b>(I) Different expressions for the same figure?</b></p> <p>Which students calculate the same area? And which of the <i>expressions</i> calculate the area of the given geometric shape correctly?</p> 	<p><b>(II) Checking for different numbers</b></p> <p>Insert different numbers for the variables. Check which of the expressions are equivalent.</p> 
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Figure 2: Tasks (I) for experiencing description and (II) for insertion equivalence (first stage)

Following the suggestions in the literature (Wellstein, 1978; Mason et al., 2005; Malle, 1993), we developed Task 1 (in Figure 2) for fostering students conceptual understanding of description equivalence: by considering four algebraic expressions of fictitious students that are to be compared, the learners are fostered to discover that different algebraic expressions can describe the same geometric shape (similarly for functions in Kieran & Sfard, 1999). Till's and Ole's expressions describe the area of the given shape, whereas Merve's and Paul's expressions do not. Task II (in Figure 2) suggests checking the equivalence by inserting numbers; this refers the algebraic expressions back to arithmetic expressions. Students who have already found out that some expressions are description equivalent can experience that they have the same value for each insertion. In this, they are supposed to construct the meaning of insertion equivalence. A later part of the teaching learning arrangement addresses the transformation equivalence, being constructed in a process of progressive schematization (Treffers, 1987). For this case study, we exclude this step in the learning pathway.

For the design within the larger design research project KOSIMA, the activities presented were embedded into a complete teaching learning arrangement (Prediger et al., 2011) that follows several central design principles.



The most important ones for this case study are:

- first construct meaning (here description and insertion equivalence), then schematize it into syntactic transformations (Freudenthal, 1991; Prediger, 2009);
- constantly relate different representational registers (Bruner, 1967; Duval, 2006) in order to foster the individual construction of meanings - here concretely switch between the symbolic register (algebraic expressions), the graphical register (geometric shapes), and the numerical register (arithmetical expressions after insertions);
- involve students in rich mathematical discussions for fostering interactive social constructions of meanings (Ernest, 1998).

The expert evaluation mainly considered the quality of implementation of these design principles with respect to conceptual coherence, cognitive accessibility, and suitability of contexts. It initiated partial designs before the next cycle started.

### Design Experiment Cycle 2a: Experimenting with selected parts of the design

For gaining empirical insights into typical challenges on the learning pathways (specification of research question Q2), we conducted two design experiments with core activities like those from figure 2, being prepared by less complex tasks in which students calculated the area of simpler shapes and wrote and interpreted algebraic expressions. The videos of students' processes were roughly analyzed with respect to typical challenges and resources. For this, the videos were categorized with respect to students' conceptions expressed in their interactions and actions.

The thematic focus "challenge of generality of expressions and geometric shapes" arose while observing Paula and Daniel (grade 9), who solved Task I in an unexpected but typical way. We briefly sketch some typical moments on their learning pathway on Task I and II (analyzed in more detail in Zwetschler & Prediger, 2013): In Task I, Paula and Daniel succeeded in checking for some expression if they correctly described the area of the geometric shape or not. When struggling with the more complex expression suggested by the fictitious Till, they decided to calculate its value and compare it to other expressions' values. As calculating the value is only possible after inserting numbers, they determined the length of the sides in the geometric drawing by counting units (a technique that might have been slightly suggested by the grid paper but also appeared without it). This technique of determining one specific number for the variables led them to a successful decision regarding Till's expression. However, the technique is not compatible with the table of different insertions given in Task II. When starting with Task II, Paula and Daniel were astonished:

- Paula We filled in the right numbers and he took any number whatever?
- Daniel Huh? That's not possible. (...)  
You just can't insert different numbers.

a	b	h	$a \cdot b + \frac{1}{2} \cdot a \cdot h$	$a \cdot (b+h)$
1	1	1	1,5	
1	2	1	2,5	
2	1	3	5	

Daniel and Paula disagreed on inserting different numbers instead of the fixed lengths of the concrete drawing. With this restriction of possible insertions, they did not get any access to Task 2 and to general insertion equivalence.

In the first analysis of the video, we recognized their problem, on the one hand, as a typical misconception regarding variables as a specific hidden number (Küchemann, 1980) and, on the other hand, as a well-known challenge in geometry (Parzysz, 1988): understanding a geometric figure as *general* instead of seeing only the concrete drawing.

We rediscovered that general formulas for areas are not at all easy to understand for students in their generality; hence this insight has to be added to the specification of learning contents (see figure 1).

As a consequence for the redesign, we developed additional activities for dealing with this challenge of generality of geometric figures and variables. Task III in figure 3 was introduced in order to let the students experience that the same algebraic expression can describe the area of different (drawings of concrete) triangles, all of them belonging to the same geometric figure (the so-called *general triangle*) and being described by the same *general expression*.

**(III) One expression for all triangles?**

a) Draw three absolutely different triangles and find a way to calculate their area by splitting and adding the drawings. Write down expressions for the three areas.

b) Can you find a general expression to calculate all three areas?

c) Can you really calculate the areas of all triangles with your general expression? Draw and try.

Possible student solution:

The student solution shows three triangles drawn on rectangular bases. The first triangle (blue) is inscribed in a rectangle with base  $g$  and height  $h$ ; its area is calculated as  $g \cdot h : 2$ . The second triangle (red) is also inscribed in a rectangle with base  $g$  and height  $h$ ; its area is calculated as  $\frac{g \cdot h}{2}$ . The third triangle (green) is inscribed in a rectangle with base  $g$  and height  $h$ ; its area is calculated as  $\frac{g \cdot h}{2}$ . To the right of these drawings, the student has written the general expression:  $\text{all } \frac{g \cdot h}{2}$ .

Figure 3: Task (III) for discovering the generality of figures and expressions

### Design Experiment Cycle 2b: Deeping the analysis on selected parts of the design

Although these first observations already informed the redesign of some elements of tasks and communicative activities, we decided to deepen the analysis with a more systematic analysis of higher methodological control in order to get deeper answers to question Q1-Q3. For this, we developed analytical tools based on Vergnaud's (1996) constructs theorems- and concepts-in-action and conducted systematic qualitative analysis of transcripts (Zwetzschler & Prediger, 2013). Within the language of this analytic tool, the observation from above would be rephrased as follows: Paula's and Daniel's reaction is guided by their theorem-in-action <For comparing two expressions, I can compare the values of the expressions>, but limited to one insertion, the lengths in the drawing. Behind this, we reconstructed their concepts-in-action Variable as specific hidden number and Shape as concrete drawing. By rephrasing all observations in the same analytic language of theorems-in-actions (see Vergnaud 1996, here marked by <...>) and concepts-in-action (marked by), we could compare the conceptions of different students.

More importantly, the analytical tools allowed us to see more systematic connections between different individual conceptions and better understand the relations between different obstacles on the pathway to a general insertion equivalence.

Rather than identifying only well-known misconceptions, we were also able to recognize Paula's and Daniel's concept-in-action Value equivalence of expressions as specific insertion equivalence as still too limited, but nevertheless an important resource on the pathway to a general insertion equivalence (cf. Zwetschler & Prediger, 2013).

In parallel to this deep analysis of data from Cycle 2a, we conducted new design experiments in laboratory settings with the enhanced learning arrangement. The aim was to definitively sharpen the research focus and to complete the prototype of the teaching and learning arrangement. We were especially interested regarding how the students could transfer their experiences from the new Task III to the later treated Task I and II.

We found interesting moments for this question in the learning pathway of Jan and Niclas (grade 7). The boys worked on Task II and later on Task I and tried first to find their own ways of calculating the area by splitting the shape. After different, but not completely correct, ideas, Niclas suggested:

58 Niclas Now I would just do that *[points to the bottom angle of the left triangle]* times that *[points to side h]*

59 Teacher Huh?

60 Niclas Uh, calculate and then that *[points to b]* times that *[points to a]* then that *[points to b]* times that *[points to a]* and then add.

At this point, Niclas described a way to calculate the area without referring to its concrete measure but to characteristics of the figure. He was guided by the theorem-in-action <For calculating the area of a shape, I can split it into areas that I can calculate>. Due to his concept-in-action Formulas for geometric areas generally apply for all concrete drawings, he identified the triangle and rectangle in the shape and calculated their area. However, Niclas' conception about the variable was still limited, as became evident when they negotiated what to insert for the variables:

63 Niclas: ...can I just do it with units, that I count this *[he first touches the lower side and afterwards the height of the triangle]* so or just six units?

...

69 Teacher: How long could they be, the sides?

70 Jan: Different, as you can actually choose, x-variable.

71 Teacher: Mhm.

72 Niclas: Or maybe one unit as one meter, that are 16 meters *[points to side a]* that are 9 meters *[points to side b, gives a shrug]*, aren't they?

At that point, both students are guided by the theorem-in-action <For calculating the area of the given shape, I can insert values for the variables>, but, whereas Jan holds the concept-in-action Variable as generalized number, Niclas still activates the concrete Variable as place holder for specific numbers.

#### (IV) Different possibilities for the shape of the terrace

The 3 x 6 m terrace shall be enlarged around the corner; the family discusses different possibilities.

- Draw two more terraces (terrassen) on your own.
- Calculate the area of the different shapes.
- Can you calculate all possibilities for the terrace by the general expression  $3 \cdot 6 + x \cdot y$ ?

Snapshot from students' solution:

Maïke calculates different terraces for evaluating c)

(1) Haus  $2 \cdot 3 + 3 \cdot 6 = 24 \text{ cm}^2 \checkmark$   
(2) Haus  $3 \cdot 6 + 4 \cdot 5 = 38 \text{ cm}^2 \checkmark$   
(3) Haus  $3 \cdot 6 + 5 \cdot 4 = 38 \text{ cm}^2 \checkmark$   
(4) Haus  $3 \cdot 6 = 18 \text{ cm}^2$   
(5) Haus  $5 \cdot 3 : 2 = 7,5 \text{ cm}^2$   
 $\rightarrow 5 \cdot 3 : 2 =$

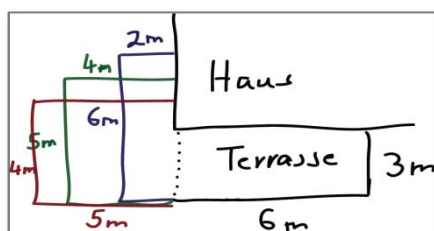


Figure 4: Task IV for coordinating generality in geometric figures and insertions

While the newly inserted Task III helped Niclas to widen his understanding of a figure in the geometric context, his understanding of the variable itself stayed still concrete. These divergent conceptions later hindered him from changing between registers so that he could not relate the symbolic and graphic register.

As a consequence of this observation for the redesign, we developed a new activity in which the generalization of variables and figures was parallelized in both registers more consequently (see Task IV in Figure 4).

This activity builds upon students' resource to insert for specific numbers (the outcome of the deep analysis to the transcripts from Cycle 2a) and widens their conceptions to more general ones.

#### Design Experiment Cycle 3: Testing the complete prototype

In the Design Experiment Cycle 3, we tested the complete prototype learning arrangement in classroom settings with regular teachers and much more learning time with respect to practicality under normal classroom conditions (especially research question Q1 and Q3). The videos and written products from classrooms were triangulated by short design experiments in laboratory settings with some students of these classes in which the focus was set to the new activities and critical moments in the process with respect to question Q2 and Q3. The aims were, on the one hand, to see how the prototype of the teaching and learning arrangement worked and to enhance the redesigned arrangement and, on the other hand, to develop the local theory regarding the learning process and its elements.

A typical outcome in terms of practicality was the observation that teachers and students had difficulties understanding the three drawings in one picture of Task IV. As a consequence for the redesign, we split a similar picture into three for the Design Experiment Cycle 4.

However, the main idea of the task served for the intended purpose very well, and, in this way, we could verify and deepen the local theory of teaching and learning different meanings of algebraic equivalence: most of the students could develop their conceptions of generality in parallel for variables and geometric figures, as the analysis of students' products in the classroom showed.

On the base of this learning success, the learning pathway towards description and insertion equivalence was opened, as the following short scene from Maïke and Jenny (grade 8) shows: having worked on tasks similar to Tasks III and IV in the classroom, Maïke and Jenny work on a tasks similar to Task I in a design experiment in a laboratory setting. Maïke reflects on how to solve the task.

- 8      Maïke:      But when we don't have such values to calculate - then we don't know if it's equal - huh?
- 9      Jenny:      She wanted to calculate that, if it's equal [*points to the expressions*].
- 10     Maïke:      Yeah, but you can't do without [without given numerical values].

Maïke wanted to use the insertion equivalence, but switches to description equivalence (see start of this section for the meaning of these concepts) when realizing that she did not have numbers to insert. Her practices seem guided by her theorem-in-action <To evaluate expressions as correct, I can calculate them or describe their connection to the figure>. She activated and combined the concepts figure as general and variable as general.

These observations were in line with the hypothesized learning pathway of understanding generality in graphical and symbolic registers as a precondition towards understanding algebraic equivalence. This was an important part of the local theory of teaching and learning algebraic equivalence.

Apart from isolated optimizations (like drawing three pictures instead of all in one, see above), the prototype teaching and learning arrangement could now be finalized in the last cycles that are not treated here in detail (see table 1).

### 3. Concluding remarks

Although the case study can only sketch selected aspects of a comprehensive, several-year-long project, it might have shown that Didactical Design Research is an ambitious endeavor in which for each of the four working areas (see figure 1), substantial theoretical and methodological background is needed. The iterative interplay between the different working areas (see figure 1) enables the researcher-designers to intensively coordinate the different working areas and to concretize the general design principle for giving students access to conceptual understanding of mathematical topics; teaching-learning arrangements should generally start from meaningful (often out-of-school) contexts, provide adequate representations, and allow students to build adequate models of the mathematical topics.

Specific to didactical research is the perspective that the learning content is not considered as pre-given. Instead, its specification and re-structuring are also an important result. For this aim, the method of mediating between students' perspectives and academic perspectives has again proven to be fruitful (Prediger, 2008; Duit, Gropengießer, & Kattmann, 2005). Here concretely, we became aware of the importance of also generalizing the geometric shapes, not only the numbers, for developing a profound conceptual understanding of algebraic equivalence.

On the other hand, it is the orientation at *feasibility in normal classrooms* that helps the designers not to overemphasize singular aspects resulting from isolated empirical projects. Although the generalization of geometric shapes is important, the learning arrangement needs to focus on many other aspects, too. For assuring ecological validity of the learning arrangements, it is crucial to triangulate the design experiments in laboratory settings by design experiments in realistic classroom settings. In this second step, experienced teachers are very important partners.

The next steps in our project will deepen the results in both directions: The design results will be implemented in a widely organized project of implementation and professional development (KOSIMA-project, see Hußmann, Leuders, Barzel, & Prediger, 2011); the research results will be deepened by another study that focuses on the transition from generational to transformational activities, the next step in the algebraic learning arrangement.

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## Design Research in Mathematics Education: The Case of an ICT-rich Learning Arrangement for the Concept of Function

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Credits



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# 21. Design research in mathematics education: The case of an ICT-rich learning arrangement for the concept of function<sup>1</sup>

Michiel Doorman, Paul Drijvers, Koeno Gravemeijer, Peter Boon, & Helen Reed

## Abstract

*The concept of function is a central but difficult topic in secondary school mathematics curricula, which encompasses a transition from an operational to a structural view. The question in this paper is how to design and evaluate a technology-rich learning arrangement that may foster this transition. With domain-specific pedagogical knowledge on the learning of function as a starting point, and the notions of emergent modeling and instrumentation as design heuristics, such a learning arrangement was designed for grade 8 students and field tested. The results suggest that these design heuristics provide fruitful guidelines for the design of both a hypothetical learning trajectory and concrete tasks, and can be generalized to other design processes.*

## 1. Introduction

The function concept is a central but difficult topic in secondary school mathematics curricula (Akkus, Hand, & Seymour, 2008; Ponce, 2007). Functions have different facets, and to make students perceive these as facets of the same mathematical concept is a pedagogical and didactical challenge. In lower secondary grades, functions mainly have an operational character, and are calculation 'engines' that process input values into output values. In higher grades, functions have the character of an object with various properties. The transition from functions as calculation operations to functions as objects is fundamental for conceptual understanding in mathematics.

Can computer tools help to foster this transition? Computer tools offer opportunities for mediating the learning activities in which students engage (Sfard & McClain, 2002). The availability of sophisticated computer tools for mathematics education, however, also raises questions. Representations (e.g., formulas and graphs) and techniques (e.g., rewriting equations) in such computer environments may signify mathematical concepts that are still to be constructed by the students. As experts, we see the mathematics in the tool use, but does the learner see this too? This inherent circularity is known as the learning paradox (Bereiter, 1985; Gravemeijer, Lehrer, Van Oers, & Verschaffel, 2002; Van den Heuvel-Panhuizen, 2003).

To design a learning arrangement that avoids the learning paradox in using ICT-tools and fosters the learning of the concept of function - and the transition from an operational to a structural view in particular - is the central issue in this chapter. In a design research study we

<sup>1</sup> This contribution is based on the following publication with permission of the editor: Doorman, M., Drijvers, P., Gravemeijer, K., Boon, P., & Reed, H. (2012). Tool use and the development of the function concept: from repeated calculations to functional thinking. *International Journal of Science and Mathematics Education*, 10(6), 1243-1267.

investigate the question of how a learning arrangement with computer tools can foster the transition from an operational to a structural understanding of functions.

## 2. Theoretical framework

The theoretical framework that guides the design in this study includes (1) domain-specific knowledge on the concept of mathematical function; (2) the notion of emergent modeling; (3) theories on tool use and its instrumentation.

### The concept of mathematical function

The teaching and learning of the concept of mathematical function is a widely researched topic (e.g., see; Carlson, Jacobs, Coe, Larsen, & Hsu, 2002; Ainley, Bills, & Wilson, 2005; Oehrtman, Carlson, & Thompson, 2008). A key issue in these studies is what Sfard calls the two sided nature of functions (Sfard, 1991, 1992). Her theory on the dual nature of mathematical conceptions identifies operational and structural concepts, the first concerning mathematical processes and the latter mathematical objects. In Sfard's view, the operational and structural conceptions are complementary. Historically, the operational aspect preceded the structural aspect, and the same might hold for individual learning processes, because the structural approach is more abstract than the operational. Dichotomies related to Sfard's operational and structural aspects have been brought afore by other researchers such as Dubinsky (1991) and Tall and Thomas (1991).

Based on an analysis of the available literature on this issue of operational conceptions preceding structural conceptions, the following sequence of three interrelated aspects of the function concept are distinguished:

1. The function as an *input-output assignment*

The function as an input-output assignment that guides the stepwise calculation of an output value for a given input value. For example, we can think of a function that converts an amount of dollars into an amount of euros, or a temperature in degrees Fahrenheit into degrees Celsius. Often, this view on function is seen as the starting point for students. An appropriate symbolic representation for this function view is an input-calculation-output chain. Figure 1 shows such a chain for calculation temperature in degrees Celsius from temperature in degrees Fahrenheit.



Figure 1: Input-output chain for temperature conversion

2. The function as a *dynamic process of co-variation*

The second aspect of the function concept concerns the notion that an independent variable, while running through its domain, causes the dependent variable to move through a set of possible outcome values. The dependent variable co-varies with the independent. Helpful representations for studying co-variation are tables and graphs, which can be scrolled through or traced. Figure 2 shows such a table for the temperature conversion example.

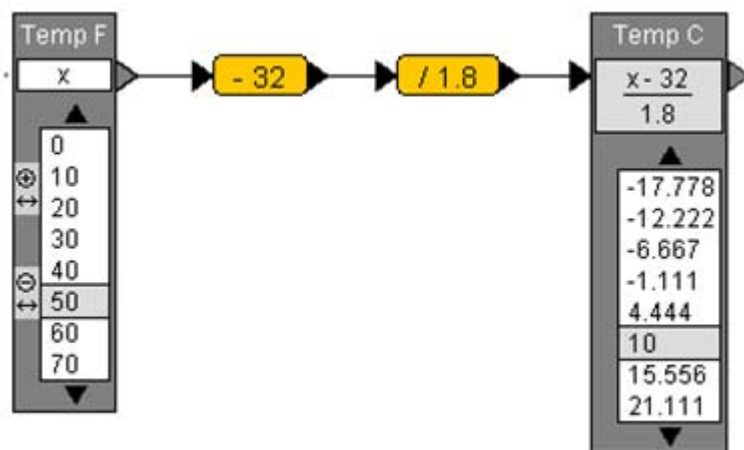


Figure 2: Table for temperature conversion

3. The function as a *mathematical object*

A function is a mathematical object which can be represented in different ways, such as arrow chains, tables, graphs, formulas, phrases, each of which providing a different view on the same object. The more structural view on functions includes families of functions, function comparison, and later on function differentiation or integration. For the object view on function, it is important to be able to see the connections between the different function representations. Figure 3 combines different representations for the temperature conversion example.

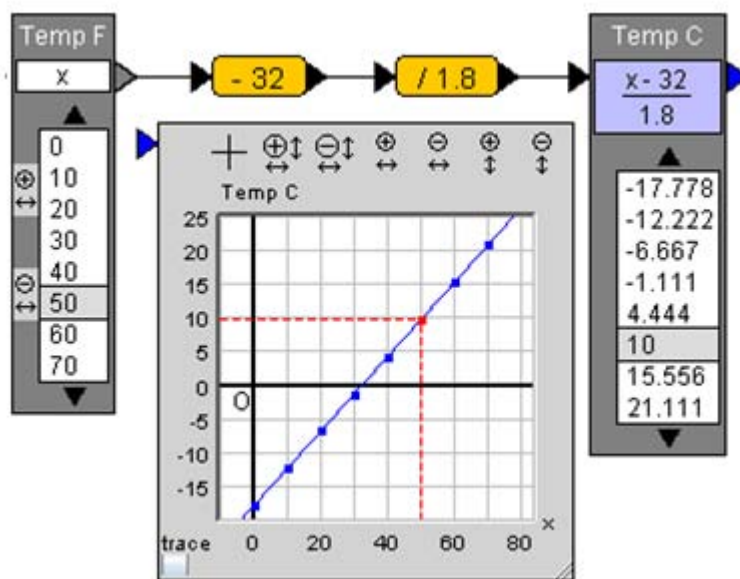


Figure 3: The different representations of the temperature conversion function

These three aspects of function reflect the operational- structural dimension as identified by Sfard (1991): the function as an input - output assignment reflects an operational conception and the function as a mathematical object involves a structural view, whereas the function as a dynamic co-variation process reflects an intermediate conception.

In line with this conceptual analysis, which is further elaborated in Doorman, Drijvers, Gravemeijer, Reed, and Boon (2012, see also Gravemeijer, Doorman & Drijvers, 2010), we want to design a learning arrangement for the topic of function that fosters the transition from an input-output conception to a more versatile view including a structural conception. This is the first design criterion. In the envisioned learning arrangement we implement computer tools with representations such as arrows, tables, formulas and graphs that initially may have hardly any meaning for students. The challenge for us - as designers - is to find ways in which these representations become useful models for the students. The notion of emergent modeling offers an orientation for addressing this challenge.

### **Emergent modeling**

Emergent modeling is a design heuristic which originated in the framework of the theory of realistic mathematics education (RME) (Gravemeijer, 1999, 2007). RME builds on Freudenthal's (1991) image of mathematics as 'a human activity': while engaging in mathematics as an activity, students should be supported in re-creating or reinventing mathematics. The emergent modeling design heuristic is a means for organizing such a *reinvention process*. The starting point is an activity of modeling problems that are experientially real to the students. Models initially are context-specific and refer to realistic or paradigmatic situations. Then, while the students gather more experience with similar problems, attention shifts towards the mathematical relations involved. This enables students to use the model in a different manner: it derives its meaning from mathematical relations and becomes a base for more formal mathematical reasoning: a *model of* informal mathematical activity develops into a *model for* more formal mathematical reasoning (e.g., Gravemeijer, 1999; Cobb, 2002; Doorman & Gravemeijer, 2009). The learning paradox described in the introduction can be circumvented by designing a chain of activities that allow for a process of emergent modeling that fosters a thinking process in which symbolizations and meaning co-evolve (Cobb, 2002; Meira, 1995). This approach is consistent with conceptual change literature, which argues that students must first explore a domain and recognize limitations or a need for more sophisticated tools, before they are ready to learn complex concepts (Lehrer & Schauble, 2002).

In this study, the notion of emergent modeling is an important design heuristic. It stresses the importance of starting with problems that offer opportunities to develop situation-specific reasoning and tentative representations for organizing repeated calculations and that have the potential to develop into more sophisticated - mathematical - tools and concepts (Gravemeijer, 2007). Taking this process of emerging models seriously asks for a design in which models *for* emerge in a natural way from models *of*, that are rooted in suitable contexts. This is a second design challenge for the learning arrangement.

### **Tools and instrumentation**

Emergent modeling as a design heuristic does not particularly focus on the use of computer tools and the relationship between computer techniques, paper-and-pencil techniques, and conceptual understanding. Drawing upon Vygotsky's view on the dialectic relation between tool use and cultural practices, we consider it important to understand and carefully plan the role of tools in a learning process (Vygotsky, 1986; Wertsch, 1998). As Hoyles and Noss (2003) point out, tool characteristics do matter in the sense that their visualizations and the available techniques affect student learning.

Instrumentation theory was developed to address the problems that may arise when one starts to use a ready-made computer tool and explains the importance of aligning techniques that emerge in contextual problems with the techniques available in the computer tool. The theory focuses on the mediating role of tools by stressing the co-emergence of tool techniques and

meaning in a process of *instrumental genesis* (Artigue, 2002; Trouche, 2004; Drijvers & Trouche, 2008). Instrumental genesis comprises the development of cognitive schemes containing conceptual understanding and techniques for using a tool for a specific type of task. The resulting instrument integrates the tool and mental schemes. A bilateral relationship between the tool and the user exists: while the student's knowledge guides the way the tool is used and in a sense shapes the tool--the affordances and constraints of the tool influence the student's problem-solving strategies and the corresponding emergent conceptions.

In the case of functions, computer tools offer opportunities to dynamically and flexibly deal with different representations such as tables, graphs, and formulas. This may help students to overcome the difficulty of construing and integrating the operational and structural aspects of the function concept and its different representations. Computer tools can support students in exploring dependency relationships and investigating the dynamics of co-variation. The third design challenge, therefore, is to shape these opportunities, while ensuring that the techniques in the computer tool match with the targeted conceptual development.

### 3. Design

The study aims at designing and evaluating an ICT-rich learning arrangement for grade 8 students (age group 13-14 year) in the Netherlands,

1. which fosters the transition from an input-output conception to a structural conception
2. in which 'models *for*' emerge in a natural way from 'models *of*', that are rooted in suitable starting points
3. and which benefits from the opportunities ICT offers, while ensuring that the techniques in the computer tool match with the targeted conceptual development.

As a first design step, a hypothetical learning trajectory (Simon, 1995) was designed based on the theoretical framework and the literature review. In this trajectory description, problem situations, models, ICT techniques and targeted conceptual development were summarized and outlined.

Next, the design research was carried out in a cyclic process of three design cycles, one pilot and two full cycles, each lasting for about one year. The learning arrangement includes (a) a computer tool called AlgebraArrows, (b) a student textbook with both paper and pencil and computer tasks, (c) a teacher guide describing the various activities and their possible orchestrations, and (d) a computer- and written test<sup>2</sup>.

The *computer tool* is an applet called AlgebraArrows, which allows for the construction and use of chains of operations (so-called arrow chains) and provides options for creating tables, graphs and formulae and for scrolling and tracing. The applet is embedded in an electronic learning environment in which tasks are provided and through which the teacher can monitor students' responses (Boon, 2009). The AlgebraArrows window is embedded in the learning environment (see Figure 4). Figures 1, 2 and 3 were also made with this applet.

AlgebraArrows is meant to support the transition from operational understanding to structural understanding the concept of function in the following manner. First, students construct input-output chains of operations to carry out calculations. The chains can be applied to single numerical values as well as to variables. Gradually, the student activities focus on the investigation of dynamic input-output dependencies. The computer tool's slider bar and table

<sup>2</sup> The trajectory description and the learning arrangement are available through <http://www.fisme.science.uu.nl/tooluse/en/>. The digital part of it can be found at <http://www.fisme.uu.nl/dwo/demo/en/>



scrolling options, in conjunction with the tasks, invite the students' development of a dynamic notion of a variable (see Figure 4). Finally, the students investigate families of functions, with their properties and representations, to develop a structural view of function. For instance, the table representation is initially understood as a tool for organizing corresponding input-output values in a contextual problem on mobile phone offers. Next, the applet's table option can be used as a tool for scrolling and zooming in on or out of these values, e.g., to analyze growth behavior or to find break-even points. This imagery of table and actions initially signifies repeated calculations and emerges into a model for a structural understanding of dependency relationships. In practice, these design considerations led to changes in the applet, such as the addition of zooming tools in the table option, similar to the zooming tools in graphs. The tool techniques are meant to relate to paper-and-pencil techniques, and as such instrumental genesis should be natural and should contribute to the targeted cognitive development.

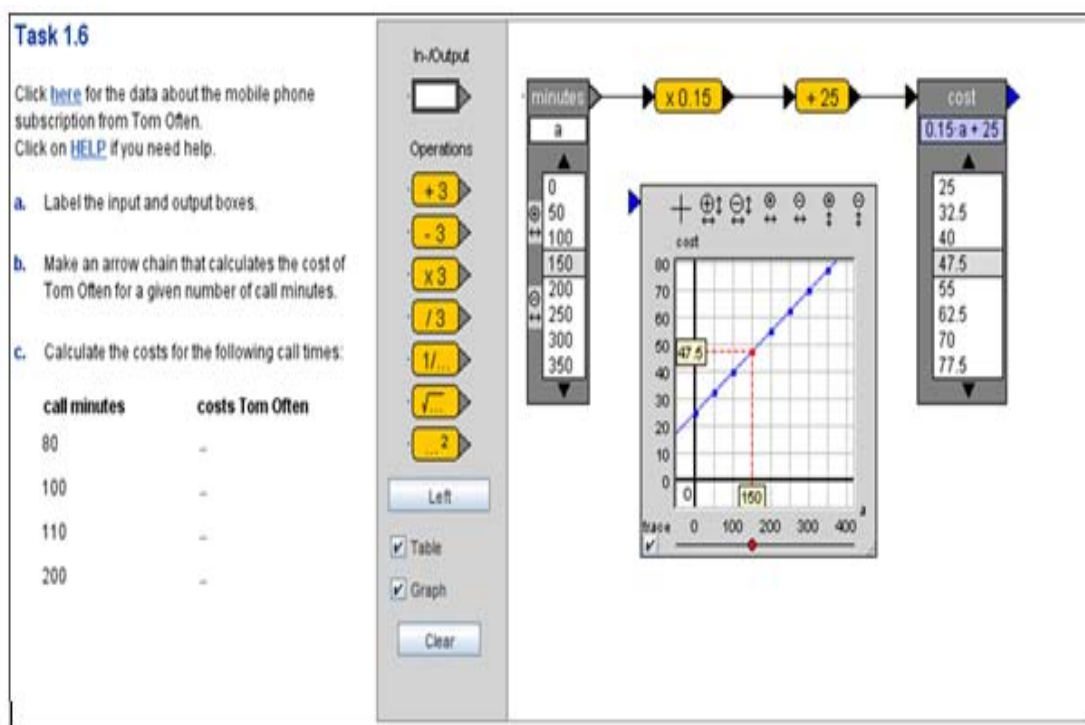


Figure 4: The computer tool AlgebraArrows embedded in the learning environment

The *student textbook* describes the activities for eight lessons. It starts with three preliminary paper-and-pencil group activities to create an exploratory orientation on the topic, to create the need for organizing series of calculations and to introduce the computer tool. In addition, these activities are designed to avoid discrepancies between tool techniques and conventional paper-and-pencil techniques and to anticipate instrumental genesis through the use of representations and techniques that will be used in the computer tool. The three successive activities are:

- Calculating the area of a flexible quadrilateral, which students explore using a paper model, and which then leads to the introduction of a variable (the height of a parallelogram) and a calculation procedure or a formula for the area.
- Comparing two cell phone offers, with a focus on break-even points which creates the need for a function-concept (Ainley, Bills, & Wilson, 2005; Küchemann, 1981).

- Calculating the braking distance of a scooter for various speeds. It includes a table-representation and is intended to create the need for graphing a trend for doing predictions. During a classroom discussion of students' solutions orchestrated by the teacher (see below), an arrow chain is supposed to emerge as a useful way to investigate input-output relationships. The arrangement continues with two computer lessons. During the computer activities, the focus shifts from solving specific situations towards the investigation of dependency relationships by means of break-even problems that ask for the generation and comparison of tables of input- and output values, and moving around in a space of possible values. According to the emergent modeling heuristic, a shift is expected to take place from sub-models that signify repeated input-output calculations to models signifying dependency-relationships, co-variation and function object properties. The arrangement continues with a reflective lesson in which whole-class discussions and demonstrations align computer techniques with paper-and-pencil techniques, a computer lesson with applications, and a closing lesson for summarizing results and creating consensus on representations and functional reasoning. The *teacher guide* describes the different activities and their possible orchestrations (Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010). It suggests different classroom arrangements, such as small group work, poster presentations, computer activities in pairs, and whole class discussions on the results, supported by projections of computer work (Stein, Engle, Smith, & Hughes, 2008). This variety of classroom arrangements is expected to foster social interaction, to promote the articulation of tool use and to enhance reflection and generalization. The final part of the learning arrangement consists of a *computer test* and a *written test*. This mixed media assessment reflects the arrangement as a whole. The written test captures transfer of learning from computer tool to conventional methods and contains questions about break-even points, and computer tasks where students could use the applet AlgebraArrows<sup>3</sup>. Test items in the two tests are comparable in length and difficulty and have similar scoring instructions.

#### 4. Research methods

To evaluate the design and to understand why the particular instructional setting potentially supports learning, design research was carried out (Gravemeijer & Cobb, 2006, 2013). The main hypothesis to be investigated is that the learning environment indeed fosters a transition from an operational view to a structural view, as reflected in the students' reasoning and in their way of using the computer tool. We briefly now describe the teaching experiments and data collection, and the data analysis.

##### Teaching experiments and data collection

After a first small-scale pilot study in one class, two successive teaching experiments were conducted in grade 8, with mid and high-achieving 13-14 year old students, for investigating their learning processes in relation to the learning arrangement. Each round of experiments took eight 50-minute lessons. The first was conducted with three classes from three different schools. The second was conducted on a larger scale. In this paper, we focus on screencast video data from pairs of students in the first teaching experiment. These students were selected by their teachers based upon criteria we provided: an average level of mathematical performance, a communicative attitude, i.e., willing to explain their reasoning and solution strategies, and audible articulation. The qualitative findings are triangulated with quantitative

<sup>3</sup> The full computer test and written test can be found at <http://www.fisme.uu.nl/tooluse/en/>

posttest data from 155 students from five classes from two different schools in the second experiment, for which the most complete data were available.

In both teaching experiments, whole class teaching sessions, group work and work in pairs were videotaped in two of the participating classes and, in each of these classes, screencast-audio videos of two pairs of students working with the computer tool were collected. In addition, students' answers and results to the written and the computer test administered at the end of the experiment were collected.

Between the teaching experiments, the learning arrangement was improved. The overall outline of the three different aspects of the function concept was not changed but fine-tuning the model-*of* to model-*for* development and the relationship between tool techniques, paper-and-pencil work and mathematical thinking was needed. In order to better investigate the development of the function concept, we placed a stronger emphasis on break-even points as a motivation for investigating the dynamics of relationships. In addition, to establish to what extent the students' final performance depended on the use of the available computer tool and to assess the transfer of learning, both a written test and a computer test were added to the end of the learning arrangement.

### **Analysis**

The data analyses started with organization, annotation and description of the data with software for qualitative data analysis (ATLAS.ti; see van Nes & Doorman, 2010). Initially, the tasks in the learning arrangement served as the unit of analysis. Factual codes (task number, student names, et cetera) were used to organize and document the data. Events in class videos and screencast videos that were notable from the perspective of the research question were transcribed and discussed in the research team.

In analyzing the first teaching experiment, we constructed a storyline as a reconstruction of the students' learning process. The qualitative data sources were discussed with two external experts to identify illuminating examples of the resultant learning process. This discussion resulted in recognizing a shift in the students' reasoning with functions. Next, illuminating and representative examples for important steps in the shift were identified. A code book was set up. Next, we distinguished solution strategies used on two similar computer tasks on break-even points that were designed for studying the development of students' reasoning with the computer tool. One task was situated at the beginning of the computer lessons and the other at the end. The strategies led to the construction of codes with respect to the use of representations in the computer tool. These codes reflected the different aspects of the function concepts, the types of tool use, and the position in the hypothetical learning trajectory. In a later phase, these codes were also used for the quantitative analyses of students' answers to the paper-and-pencil activity concerning the arrow chain (the booklets of 5 students were missing), the screenshots of the answers to the two computer tasks, and the screenshots of students' final work on the two computer tasks. A second researcher coded 55 out of 306 items (18%). Good inter-rater-reliability was achieved (Cohen's Kappa = 0.79). A paired *t*-test was used to compare the results on the written test and the computer test.

## **5. Results**

The results of the study are presented in the form of a storyline of students' learning process in relation with the learning environment, as reflected in their reasoning and in their way of using the computer tool. This storyline offers opportunities to trace the development of our interpretations and understanding of these learning processes. This approach is linked to Smaling's (1987) view on 'trackability' and to Freudenthal's notion of 'justification' (Freudenthal,

1991). The storyline is illustrated with examples of student work and is also supported by the quantitative findings.

### The initial cell phone offer task: organizing calculations

The results of the initial open-ended group activities of the first teaching experiment show a variety of solution strategies. In Figure 5 (top) the cell phone offer task is shown. The students' posters below are illustrative for their attempts to organize the situations mathematically, i.e., to organize repeated calculations, construct variables and use various representations. In the poster on the left, students organize their repeated calculations by systematically writing them in a list, which resembles an input-output relationship. This helped them to see the pattern in the calculation, and to apply this pattern to a new input value. In the right poster, students use formulae to describe their repeated calculations. Although not in conventional form, the formulae show the identification of the two variables of the dependency relationship ( $m$  for minutes and  $b$  for costs). The repeated calculations reflect how the operational aspects precede the structural aspects of functions (Sfard, 1991). From an emergent modelling perspective, the context apparently provides a suitable starting point.

Two offers of a cell phone company:

- Tom Seldom: monthly subscription charge € 7.50, plus 25 cents per call minute. The first 30 call minutes are free.
- Tom Often: monthly subscription charge € 22.50, plus 15 cents per call minute. The first 80 call minutes are free.

Nadia calls circa 100 minutes per month. Which offer should she choose, Tom Seldom or Tom Often?

Find a way to show how the costs of Tom Often vary when you call less or more minutes each month.

Handwritten calculations (left poster):

$$104 - 30 \times 0,25 + 7,5 = 26$$

$$104 - 80 \times 0,15 + 22,5 = 26,1$$

$$105 - 30 \times 0,25 + 7,5 = 26,25$$

$$105 - 80 \times 0,15 + 22,5 = 26,25$$

$$106 - 30 \times 0,25 + 7,5 = 26,50$$

$$106 - 80 \times 0,15 + 22,5 = 26,40$$

Handwritten calculations (right poster):

Tom Seldom:

$$100 - 30 = 70$$

$$70 \times 0,25 = 17,50$$

$$17,50 + 7,50 = 25$$

Tom Vaak 8:

$$100 - 80 = 20$$

$$20 \times 0,15 = 3$$

$$22,50 + 3 = 25,50$$

Tom Seldom > Tom Vaak 8

$$m - 30 = ? \times 0,25 + 7,50 = b$$

Tom Vaak > Tom Seldom

$$m - 80 = ? \times 0,15 + 22,50 = b$$

Figure 5: Cell phone offer task and students' poster

### Introducing arrow chains: visualize functions

In a whole-class discussion, the posters helped the teacher to evoke the need for determining variables, dependency relationships and more efficient notations and tools for finding break-even points. The teacher exploited the students' strategies by linking their initial ideas to the intended tool use. A new mathematical goal emerged: repeated calculations are time-consuming, what is the general pattern in the calculation procedures? How can this pattern be described to calculate results 'automatically'? How could a 'calculator' help in comparing cell phone offers? A calculation recipe comprising a fixed chain of operations emerged. This arrow chain is the central representation of the computer tool. In the last activity before the computer lessons, the students were asked to draw calculation chains for the two cell phone offers. Figure 6 shows an illustrative answer to this task.

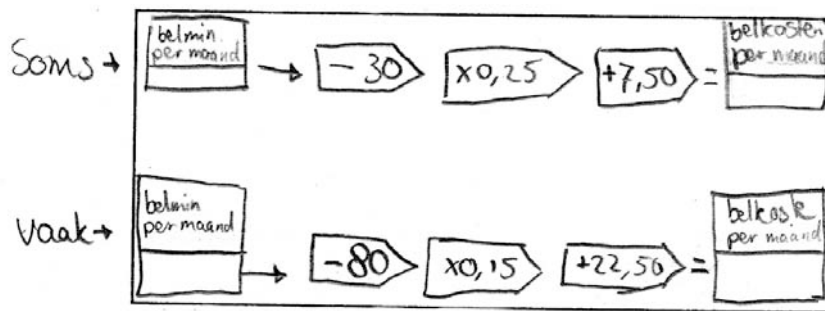


Figure 6: Written calculation chains for cell phone offers (called 'Soms' and 'Vaak').

The arrow chain as a model of repeated calculations appeared to be grounded in students' previous activities and could begin to function as a mathematical model *for* (in terms of the theory of emergent modeling) reasoning about dependency relationships. This assumption is backed up with an analysis of the results of student booklets from the second experiment. The analysis shows that 124 out of 150 students (83%) drew a similar chain while another 8 (5%) drew this chain, but used it only for one specific calculation and did not label input and output boxes. From an instrumental genesis perspective, the tool techniques were prepared for by paper-and-pencil work.

#### **Using the computer tool to create arrow chains**

The third lesson - the first computer lesson - started with some introductory activities and then continued with the cell phone problem (Figures 5 and 6). The task was to determine, with the computer tool at hand, when it is advisable to change from one offer to the other. Two students, Lily and Rosy, worked together on this task. After reading the problem on the computer screen, they started to construct arrow chains with the computer tool.

[Rosy drags an input box into the drawing area. The box is connected to the operation - 80 and that one is connected to  $\times 0.15$ .]

Lily: And that added to the fixed costs.

[R agrees and connects the chain to + 22.5. Finally, they connect the chain to an output box.]

L: Well, when you phone for 100 minutes....

[enters 100 as input in both chains. TomSeldom (Soms) is cheaper than the other offer.].

R: .... Well, maybe 50.

[L enters 50 as input for both chains. They look at the results and are still not satisfied. They try some more input values. Finally, they enter 200 in the input box of both chains. For the first time TomOften (Vaak) is cheaper than the other offer. They are satisfied with this result and proceed to the next task.]

The vignette illustrates how the arrow chain has become a means to organize the situation and the calculation procedure. Lily and Rosy built the chain from the input box, adding operations and finally connecting an output box. This construction signifies their previous calculations. They focused on specific cases by entering respectively 100, 50 ... and finally 200 for comparing the differences between the two offers. The arrow chain is used for repeated calculations. The tool supports the construction of these chains, and the chain becomes a means for analyzing and discussing relationships and successive operations, as a sequel to merely solving repeated calculations. The tool technique clearly is linked to the students' paper-and-pencil experience and supports their thinking.

### **Whole-class discussion capitalizing on hands-on experience**

The start of the second computer lesson (the fourth in the learning arrangement), consisted of a teacher-guided classroom discussion of students' computer work with the computer tool connected to a data projector. Topics of discussion were the possibility to label input and output boxes and to use tables. These tool techniques were already used by some of the students, and now became 'institutionalized' through the whole class discussion. The teacher started the discussion with an arrow chain for one of the cell phone companies:

Teacher: I heard different ways to find out how much I have to pay, how the amount changes, how can you demonstrate that? [Silence] For example, if I call 10 minutes. How can I find out how much I pay for 10 minutes?

Student 1: Put 10 in the input box.

Teacher enters 10 into the input box. This gives an odd result (first 30 free minutes are subtracted). The result is discussed and the teacher varies the input by entering some more values.

Teacher: Suppose I want to know the output from many input values, what more can I use?

Student 1: The table.

Teacher clicks the table tool and shows how you can scroll through the input and output values.

Teacher: Does anyone know another way to show how the output values change for different input values?

Student 2: With a graph...

After this suggestion the teacher opened the graph tool. She demonstrated how to connect an arrow chain to the graph window. Together with the students she investigated the options to trace a graph and to zoom in and out. In this way, while demonstrating the tool techniques, the teacher discussed the dependency relationships and the ways tables and graphs can be used to analyze their dynamics. In the previous computer activities, Lily and Rosy did sometimes click for a table or graph, but had not used it for scrolling or tracing values.

This observation shows how the teacher used the computer tool to create whole-class consensus on how to use it for investigating dependency relationships. Both the techniques and related concepts were part of the discussion. She did not show how to use these features for finding break-even points. That was still a task for the students.

### **A different view on function**

During the third computer lesson (the sixth lesson of the learning arrangement), we observed that the strategy of Lily and Rosy for using the computer tool had changed while solving a task on two offers by contractors called Pieters and Tweehoog (Figure 7).

To get some jobs done in the house we can choose from two contractors:  
Contractor "Pieters" charges 92 start costs and an hourly rate of 30.  
Contractor "Tweehoog" charges 45 start costs and an hourly rate of 32,75.  
You have a job of 9 hours. How much cheaper is Tweehoog than Pieters?  
After how many hours of work is contractor Pieters cheaper than Tweehoog?

*Figure 7: Handyman task offers*

The task in Figure 7 is quite similar to the cell phone activity (Figure 5). However, the way in which these students analyzed the problem situation, phrased the structure of the solution procedure and used the representations in the tool changed: AlgebraArrows was now used to

investigate the dynamics of relationships, rather than for case-by-case calculations. Figure 8 shows some subsequent phases in these students' work.

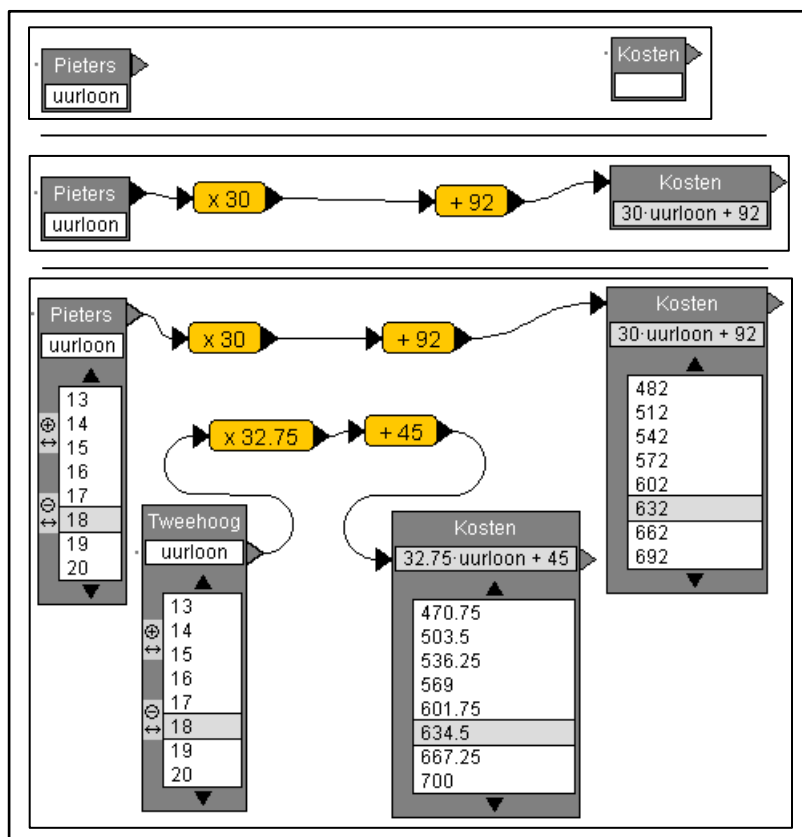


Figure 8: Different phases in students' work

First, the students identified the variables by creating labeled input- and output boxes for the first arrow chain, with 'uurloon' meaning hourly rate and 'Kosten' for costs (Figure 8 top). Next, they filled in the operations and completed the chain (Figure 8 middle). Then they constructed the second chain for the Tweehoog company in similar way. Finally, they added tables, and scrolled through them to find the break-even point for 18 hours (Figure 8 bottom part). This behavior illustrates a different view on, and use of, the arrow chain compared to the initial operational left-to-right construction of a chain for repeated calculations. More specifically, the vignette illustrates how the arrow chain had become a tool for analyzing dependency relationships. Lily and Rosy organized the dependency relationship by identifying, positioning and labeling boxes for input and output variables and filling the gap between them with operations. This construction signifies an understanding of the problem as a question about two dependency relationships. For investigating the dynamics, they successfully operated the table tool to zoom in and out for finding the break-even point. Corresponding to this new view on function, the technique of constructing an arrow chain changed, now starting with labeled input and output boxes rather than with input and then operations. This suggests a structural view on function.

### ***Triangulating case study findings with computer output***

The second teaching experiment was used to quantitatively verify the hypothesis on the transformation of the view on function during the computer activities. We found that for the initial task 130 out of 155 students (84%) used the tool only for calculating successive input-output values, while in the task at the end, 89 out of 152 students (58%) used the tool for structuring and investigating the dynamics of the relationships.

Whereas the students' initial technique with the applet suggested an operational view on functions, this more advanced technique reflects a transition towards a gradually developing structural view. In other words, the shift in the use of the tool reflects the development from viewing calculation recipes as tools for repeated calculations (as processes) towards reasoning with structural characteristics of dependency relationships (as objects).

To investigate whether this transition also encompassed students' written work during the eight lessons, we compared the scores of the computer test and the written final test. A paired *t*-test showed no significant difference ( $p=0.20$ ) between the final scores on the written test and the computer test. The Pearson correlation coefficient of 0.38 between these scores was moderate ( $p=0.001$ ). This suggests that students who improved their reasoning through the described shift evoked by the use of the computer tool were able to transfer learning to a more conventional paper-and-pencil test.

## **6. Conclusion and discussion**

### **Conclusion**

In the introduction, we raised the question of how a learning arrangement with computer tools can foster the transition from an operational understanding to a structural understanding of functions. From the data analysis, we see the following characteristics of the learning arrangement as decisive for fostering a transition from a calculation understanding to working with correspondence and co-variation:

- The three initial open-ended problems and the poster activity helped students in coming to see input-output structures in problems about dependency relationships and to use representations to explore them.
- By enabling students to design and use arrow chains as a means of support for reasoning about calculation procedure that bear meaning in everyday-life phenomena, the computer tool supported the students in developing the notion of a chain of operations.
- By generating the results of a series of calculations for a variety of input values, the computer tool strengthened the students' notion of a function as a calculation procedure that transforms input values into output values.
- By generating output values for series of input values, by generating tables of input and output values, and by enabling the students to move up and down the values in these tables, the computer tool supported the students in developing a dynamic notion of a variable that can move in a space of possible values, and the corresponding idea of co-variation.
- By displaying arrow chains, tables and graphs the computer tool offers representations, which the students could construe as affordances to start treating functions as objects before they had become objects for them. In this way, the learning paradox may be circumvented.
- By discussing students' work with the tool and showing specific features that some of the students discovered, the teacher appeared successful in supporting most students in using the table representation.



We conclude that the learning arrangement with a computer tool helped students to overcome the difficulty of integrating operational and structural aspects of the concept function and supported explorative activities for investigating the dynamics of co-variation, even though the students didn't reach the full level of "function as a mathematical object" but just began to make the transition towards this level of understanding. Further advances in this direction would encompass, for example, more different types of functions and operations on functions such as composition and multiplication.

### **Discussion**

Before discussing the design heuristics of this study, we first address its limitations. The sequence of eight lessons fostered conceptual development in the domain of functions. However, the final test data do not give insight in whether *all* students made a similar step towards a dual conceptualization, with procedural and structural views, of functions. Students' work during the computer lessons revealed that the final screenshots of an activity sometimes are only approximate representations of the students' reasoning. Students can be close to a good answer and then delete everything as a result of a sudden doubt. Final screenshots don't capture this entire reasoning process. Additional process information is needed for a full understanding of students' conceptual development in relation to their tool techniques, although a balance must be found between the extensiveness and the manageability of the data collection.

As a final issue, we mention the generalizability from design-based case studies (Yin, 2003). We agree with Plomp and Nieveen (2009) that the results of design research have an analytical generalizability and a replication logic: the findings in this case may not be directly generalizable, but the design experiment may be treated as a paradigm case (Gravemeijer & Cobb, 2006, see also this volume), which offers domain-specific design heuristics that can be extrapolated to similar design studies. The extensive description of the interventions in Doorman, Drijvers, Gravemeijer, Boon, & Reed (2012) is intended to enable researchers to reenact the experiment in other settings as a way to evaluate our findings and to contribute to the development of a more comprehensive theory.

In retrospect, how do we view the three theoretically based design heuristics described in section 2? First, we used domain-specific theories on the acquisition of the concept of function, and on the transition from an operational to a structural conception in particular. This design heuristic was fruitful for outlining the learning arrangement. It had an important impact on setting up a hypothetical learning trajectory and on the design of the tasks. This particular design heuristic can be generalized into an overarching one, which is that - before engaging in design - a deep analysis of the topic is needed to be able to identify its learning obstacles and pedagogical challenges and to outline a learning trajectory.

A second design heuristic was the notion of emergent modeling, and its focus on the shift from model-*of* to model-*for*. This heuristic not only guided the design of the learning arrangement, but the students' cognitive development, and their ways of using the tool initially as a tool for calculations and later as a tool for reasoning with function, reflects this shift. As such, this was a suitable design heuristic.

Third, instrumentation theory focuses on the interrelated development of techniques and concepts. As a design heuristic, it fostered a careful integration of computer activities and paper-and-pencil activities, which prevented discrepancies between tool techniques and conventional methods. The process of instrumental genesis was enhanced by the alternation between classroom discussion, small group activities and computer activities.

Altogether, while outlining the hypothetical learning trajectory and designing the tasks the three design heuristics provided important and concrete guidelines. Having a set of such design

heuristics is indispensable, but in the meanwhile does not guarantee a successful design: it is not just knowledge of appropriate design heuristics, but their application in different domain-specific situations that forms the heart of the 'art' of the designer.

## Acknowledgements

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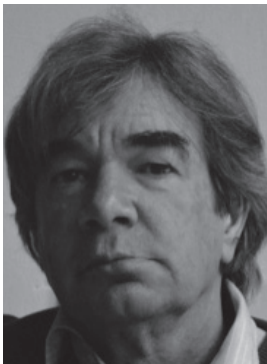
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## A Design Research into Fostering Communities of Learners for Students in Pre-vocational Secondary Education

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## 22. A design research study on fostering communities of learners for students in prevocational secondary education

Annoesjka Boersma, Karen Krol, Geert ten Dam, Wim Wardekker & Monique Volman

### Abstract

*In this chapter, the use of communities of learners in prevocational secondary education is investigated via design research. We aimed to translate theoretical notions about communities of learners into educational practice during two years of joint design by teachers and researchers, a process supported by one of the school's leader. We expected communities of learners to enhance students' quality of and engagement in learning. In this chapter, we provide a detailed review of the first year of our study at one of the schools, where we developed and evaluated two curriculum units. We focus on how the teachers collaborated with the school leader and the researchers to develop curriculum units that would foster communities of learners and how (developing and implementing) the curriculum units affected student learning. Data were collected through observations of all the meetings of the development team, all the lessons of the implemented units, and interviews with teachers and students. The results show that the teachers' focus was mainly on designing engaging activities for their students. The community of learners concept did not seem to become meaningful for them, and little reflection on the concept's relationship to the school's vision regarding teaching and learning occurred. The second curriculum unit succeeded better at promoting student learning in the intended way; the units became part of the regular curriculum, and similar units were developed later.*

### 1. Introduction

The 'community of learners' concept has become increasingly popular in educational discourse. It evokes images of harmonious collaboration, vivid dialogue, and highly motivated students who actively participate in deep and meaningful learning. Nevertheless, communities of learners have only minimally emerged in actual classroom practice. For many teachers, organising a community of learners entails considerable effort, with an unclear outcome at best. For teachers to realise the potential of the community of learners concept, they must understand the practical value of such a community.

The design research study reported in this chapter aimed to *elaborate the community of learners concept for use in prevocational secondary education*. For two years, Dutch researchers and teachers jointly designed, developed, and evaluated curriculum units for the ninth grade vocational subject Care and Welfare that would foster communities of learners in the classroom to enhance students' quality of and engagement in learning. At the two participating schools, a school leader supported the teachers to ensure that their efforts would be linked to school development. In addition to developing an innovative intervention, we aimed to identify and refine a number of heuristics that might help others put communities of learners into practice. A second aim of the study was to *provide insight into the curriculum unit development process by the teachers in collaboration with the school leader and researchers*, as we assumed that collaboration would affect the development of curriculum units that foster a community of learners for vocational orientation.

Our design research entailed three phases: 1) a preliminary phase, which included analysing the context and problems of prevocational teaching and learning and developing a conceptual framework of communities of learners for students in prevocational secondary education; 2) a descriptive phase, in which the conceptual framework was checked against the educational practices of the two participating schools to validate the usefulness of the framework and determine the state of teaching-learning processes at the schools; and 3) a dual and cyclical development and evaluation phase, consisting of a) a first year, in which at each school, two curriculum units were designed, carried out, and formatively evaluated regarding design heuristics and students' quality of and engagement in learning and b) a second year, in which the first year's units were optimised and carried out, followed by a formative and summative evaluation that focused on design heuristics and students' quality of and engagement in learning.

This chapter begins with a brief outline of Dutch prevocational secondary education, the context of our study. Next, our conceptual framework is described and research questions are formulated, followed by an overview of how we set up our design research study. In the results section, we narrow our focus to the design process and the resulting curriculum units at one school in the first year of the study, i.e., phase 3a, which clearly illustrates our design research approach. In conclusion, we describe both the practical and scientific yield of our community of learners project in a discussion of the results, and we reflect on our design research approach.

## 2. Context and problems of prevocational secondary education

In the Dutch secondary education system, prevocational secondary education complements general secondary education (see Figure 1). At age 12, students enter both education types, each including half of all students. The central aim of prevocational secondary education is to further develop students' general competences (e.g., language, mathematics) and to prepare them for senior secondary vocational education. As such, vocational orientation is a crucial aspect of prevocational learning. Students complete a core curriculum in the first two years; afterward, students from age 14 years onward continue their education in one of four vocationally contextualised sectors: Engineering and Technology, Care and Welfare, Business, and Agriculture.

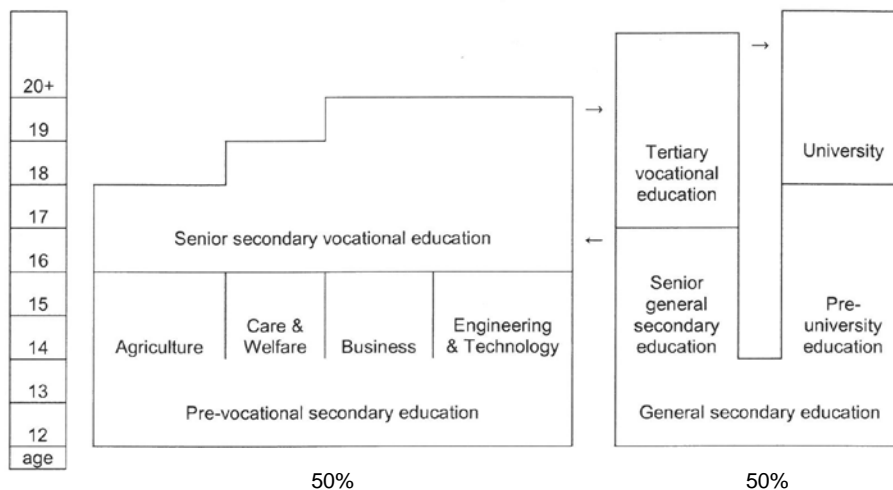


Figure 1: Overview of the Dutch system of regular secondary and tertiary education (adapted from Boersma, Ten Dam, Volman, & Wardekker, 2010)

In these sectors, teaching and learning are mainly organised in (simulated) workplaces inside and outside the school to allow students to experience working in a particular vocational area. An analysis of the prevocational teaching and learning context in these sectors revealed several problems (phase 1). In simulations, students are often not introduced to social and cultural aspects of the workplace, and the exigencies at most real workplaces leave students little opportunity to retreat and reflect. Moreover, although schools for prevocational education aim to prepare students for their futures, many students do not appreciate the value of school-based learning.

### 3. Conceptual framework

We argue that to facilitate vocational orientation and student engagement, school and work should be integrated as contexts for learning. Students should have the opportunity to participate in vocational activities that are designed to offer space and intellectual instruments for critical reflection on associated vocational practices and students' abilities and affinities regarding these practices. Based on the literature about 'communities of learners' (Brown & Campione, 1994) and 'communities of practice' (Wenger, 1998), we distinguished four interrelated parameters to define a 'community of learners for vocational orientation' in the first phase of the study: shared learning, meaningful learning, reflective learning, and learning for transfer. The four parameters are elaborated in Boersma, Ten Dam, Volman, and Wardekker (2010, p. 9) as follows:

*Shared learning* refers to a learning environment in which students jointly strive to reach a shared goal. In a community of learners for vocational orientation, students and teachers ideally work co-operatively, as colleagues working at an institution or company helping clients. The students are regarded as peripheral but legitimate members, and teachers and professionals are considered experienced members of the community (Lave & Wenger, 1991; Rogoff, Goodman-Turkianis, & Bartlett, 2001). All the community members interact and share knowledge to attain their goal, thereby acquiring new knowledge, skills, and attitudes, both individually and as a group.

*Meaningful learning* refers to the use of learned information to benefit society by working in society in the future and to benefit the students personally. Students are supposed to develop competences in school that are indispensable to society. Nevertheless, students do not always understand the importance of developing these competences in line with their personal goals and lives. In our envisioned community of learners for vocational orientation, students participate in authentic vocational practices. They then frequently experience an inability to participate fully in these practices because of faulty or missing competences. The assumption is that this experience and the students' wish to be part of the community of vocational practice make students realise that the competences our society requires are in fact competences that they themselves need.

*Reflective learning* refers to the need for students to reflect on the content of what they are learning and the processes through which that learning takes place. 'Learning through participation' is not just a matter of participating; if students are to develop competences and a professional identity, the quality of participation should be improved through reflection. A community of learners for vocational orientation ideally prompts reflection at three levels. First, students are encouraged to reflect on the way they function and develop as beginning professionals in a particular work sphere. Second, students are encouraged to think critically about the importance of the profession for society. Third, students are encouraged to realise what being a professional within the work sphere means to them.

The last parameter is *learning for transfer*. Students should be made aware that the concepts and processes they are introduced to are generative and useful across many settings

(Campione, Shapiro, & Brown, 1995). In a community of learners for vocational orientation, students ideally acquire competences in the context of their intended use, i.e., a certain vocational practice. Students construct new knowledge, identities, ways of knowing, and positions in the world. They become someone new (Beach, 1999). When they become aware of these changes, students are able to use their new identity in other contexts. They themselves are then the bridges between different settings. The implication is that students should be encouraged to reflect on *why* they need to learn certain concepts or ways of doing things and *how* this learning relates to their lives as future professionals.

In the second phase of the study, we used the parameters of our conceptual framework of a community of learners for vocational orientation to analyse whether and how these parameters were already manifested in the teaching-learning processes in the ninth grade Care and Welfare classes in the two schools participating in our study (see Figure 2). At both schools, the learning environment for this vocational subject largely consisted of simulated workplaces. Students between 14 and 15 years old learned in small groups based on theoretical and work-related practical assignments associated with each of the simulated workplaces (i.e., Welfare, Housekeeping, General Services, Care Assistance, Beauty Care, and Workplace Assistance). The practical assignments were rather prescriptive, focusing on technical aspects (for example, learning to bathe a baby was guided by a worksheet with step-by-step instructions regarding how to check the water temperature and how to lift the baby) rather than the wide array of vocational practice aspects (for example, the Western cultural value of intentionally stimulating a baby's development by interacting with the baby during bathing). Moreover, the tasks were isolated from related tasks within the vocational practice (for example, informing parents about their baby's diarrhoea), which limits students' insight into the task's purpose. The practical assignments aimed to complement the theoretical assignments, but students were not explicitly encouraged to relate their practical experience to theoretical knowledge and vice versa. From our analysis, we concluded that shared learning and meaningful learning were only partially manifested. Little evidence was found of reflective learning and learning for transfer. The dialogue with the teachers concerning these findings enabled us to identify starting points (tentative heuristics) for designing curriculum units, i.e., series of lessons that foster communities of learners for vocational orientation (for further results from the preliminary and descriptive phases, see Boersma et al., 2010).

In this chapter, we focus on the third phase of our study, specifically the design process and the resulting curriculum units at one school during the first year of development and evaluation. This first year clearly illustrates our design research approach, in which experienced teachers, who were motivated to participate in the study, were invited to collaborate with the school leader and researchers on equal terms (see 'Research design' below). We used this approach to support the development of curriculum units that foster a community of learners for vocational orientation. We address the following research questions:

1. How did the teachers collaborate with the school leader and researchers during the process of developing curriculum units that would foster communities of learners for vocational orientation?
2. Did the implemented curriculum units promote student learning in the intended shared, meaningful, reflective, and transfer-oriented way?

The answers to the first research question will contribute to our aim of providing insight into the process of developing curriculum units. The answers to the second research question will contribute to our aim of investigating the potential of the communities of learners concept for use in prevocational secondary education.

## 4. Research design

To understand the nature of our design research, some ideas that underlie our approach need to be explained. The teachers and leaders in the schools and the researchers were equally in charge of our joint endeavour (designing curriculum units that foster communities of learners for students). In addition to the theoretical input provided by the researchers, teachers' practical knowledge was valued in accounting for the contextual factors that affect teaching and learning. This practical knowledge would contribute to the realisation of ecologically valid curriculum units and the implementation of the units as intended. These aspects are essential for allowing the researchers to draw valid conclusions about the curriculum units' influence on students' learning. Thus, the design process was not pre-determined by the researchers but shaped by the teachers and school leaders. We expected our approach to help teachers and school leaders develop ownership of the designed curriculum units. To guarantee that the designed curriculum units would be closely related to the schools' vision regarding teaching and learning, the school leaders were involved in the study.

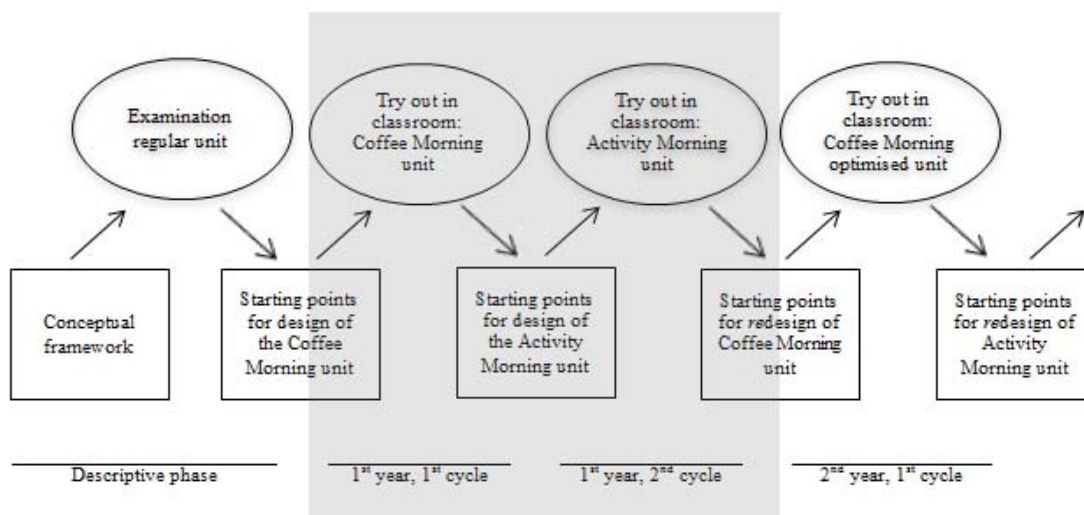


Figure 2: Overview of the first year of development and evaluation (the grey part, phase 3a), as situated between the descriptive phase (phase 2) and the second year of development and evaluation (phase 3b)

The grey part of Figure 2 provides an overview of the first year of development and evaluation for one of the schools. The first year consisted of two cycles of curriculum unit design, implementation, and evaluation. The evaluation outcomes of the first design cycle (curriculum unit 1: Coffee Morning unit) were applied in the second design cycle to create a second curriculum unit (unit 2: Activity Morning unit) that would better foster a community of learners for vocational orientation. In the second year, both these curriculum units were optimised, implemented, and formatively and summatively evaluated.

In both design, implementation, and evaluation cycles at the school, two teachers, one school leader, and two researchers were involved. Table 1 presents the development team's activities during the phases of each cycle.

To answer the first research question (on the curriculum unit development process), we gathered data on all the actions of and interactions among the researchers, school leader, and teachers during the design process of both cycles. All the *design hours* of the Care and Welfare teachers and the researcher; the *joint meetings* of the teachers, the researchers, and the school

leader; and *school wide occasions*, such as study days, were reported. These reports were submitted to and approved by the teachers and/or the school leader. A second researcher acted as the observer during several design hours and all the joint meetings to substantiate the researcher's interpretations and provide feedback to the researcher and school leader during the design hours. Using member checks of the written reports and a researcher as an observer, we enhanced the intersubjectivity of this study.

Table 1: Overview of activities during both cycles

<b>Coffee morning unit</b>		
Design (10 weeks)	Implementation (3 weeks)	Evaluation (4 weeks)
The teachers and researcher spent 16 hours designing the curriculum unit for the students. The teachers, researchers, and school leader spent 3 hours in joint meetings.	The implemented curriculum unit comprised 15 lessons in total, in which students prepared for, executed, and reflected on an event with elderly people.	The researchers and teachers evaluated the design and implementation phases in four 3-hour meetings.
<b>Activity morning unit</b>		
Design (14 weeks)	Implementation (4 weeks)	Evaluation (2 weeks)
The teachers and researcher spent 25 hours designing the curriculum unit for the students. The teachers, researchers, and school leader spent 7 hours in joint meetings.	The implemented curriculum unit comprised 40 lessons in total, in which the students prepared for, executed, and reflected on an event with primary school children.	Researchers and teachers evaluated the design and implementation phases in four 3-hour meetings.

To answer the second research question (on student learning), the reports of the design hours and the resulting lesson materials were gathered to determine how the parameters of a community of learners for vocational orientation had been incorporated into the designs. In addition, all the lessons were video recorded and separately evaluated in the teachers' and students' interviews to determine how the parameters were manifested in the implemented curriculum units. All the evaluations were voice recorded and fully transcribed. The written accounts of the design hours and the joint meetings and the transcripts of the evaluations with the teachers were systematically analysed using Miles and Huberman's (1994) matrix-display technique. The analysis consisted of three concurrent flows of activity: data reduction, data display, and conclusion drawing/verification. During the data reduction process, the written accounts of the design hours and the transcripts of the evaluations were reduced to the core. Fragments of the written accounts and transcripts were placed in a two-dimensional matrix with time on the horizontal axis and relevant themes (among which are the parameters of a community of learners) on the vertical axis<sup>1</sup>. The researchers identified categories and patterns based on the condensed matrix and drew conclusions. The researchers verified these conclusions by reviewing the raw data once more. During this process, we actively looked for examples and counterexamples.

<sup>1</sup> An example of the matrix can be obtained from the authors.

## 5. Results

In this section, for each of the two curriculum units, we first describe the design process and the resulting curriculum unit and then evaluate the collaboration of the teachers with the school leader and researchers during this process (research question 1) and student learning during the implemented curriculum units (research question 2) at one school during one (the first) research year.

### **Design process of curriculum unit 1: The Coffee Morning unit**

The teachers, researchers, and school leader jointly shaped the process of design of the Coffee morning unit. The design process involved three steps: 1) creating a rough plan, 2) elaborating learning goals, learning content, and learning activities and assessing students' learning outcomes, and 3) checking the four design parameters.

#### ***Step 1: Creating a rough plan***

During a brainstorm session, the two teachers proposed organising an event for elderly people that would give students the opportunity to talk with the elderly and participate in activities with them. Elderly people are an interesting target group for Care and Welfare students' vocational orientation because the students may work with the elderly in their future workplaces. The teachers focused on how to organise the Coffee Morning unit in terms of both the event and the consequences for the regular curriculum. After several practical considerations were discussed, it was decided that the curriculum unit would be embedded in the regular lesson plan. The researcher tried not to disrupt the teachers' enthusiasm and remained open to their ideas and approaches. The school leader supported the idea of inviting the elderly people to the school because this activity would provide an authentic experience for the students, which was in line with the schools' vision regarding teaching and learning.

#### ***Step 2: Elaborating learning goals, learning content, and learning activities and assessing student's learning outcomes***

After creating a rough plan, the teachers focused on determining what activities would be appropriate for students to undertake with the elderly people. The teachers proposed activities that were mainly inspired by the worksheets used in the regular curriculum: serving coffee and cake, polishing shoes, painting fingernails, and playing a game. Thus, the regular classroom curriculum was the teachers' starting point for the design. They did not explicitly define the goals or how to assess student's learning outcomes. The researcher guided the process by asking which competencies students should develop and what kinds of tasks would contribute to this aim. Because the teachers found answering these questions difficult, the researcher elaborated on competence-based learning. In addition, the researcher gave examples of how the design parameters were already incorporated in the regular worksheets and how to further incorporate them. During two joint meetings, the school leader encouraged the teachers to reflect on the design parameters and noted that the teachers may consider the students' opinion regarding the event, emphasising the importance of meaningful learning. As a result, the teachers asked the students to complete a worksheet elaborating an activity they would undertake with the elderly people.

#### ***Step 3: Checking the four design parameters***

The researcher took the initiative in incorporating the design parameters presented above during three of the four design meetings and tried to involve the teachers by posing questions. The third design meeting was devoted to determining to what extent the four parameters were rooted in the design. The researcher concluded that the parameters were present in the overall



design but proposed alternatives regarding how to incorporate these parameters into the regular worksheets. Although the teachers appreciated this input, the suggestions were only partly implemented, mainly by the researcher herself. The teachers were clearly focused on other aspects of the design process, indicating the teachers' limited understanding of the parameters to that point. In two meetings, the school leader emphasised the importance of vocational orientation. By participating in professional activities during the Coffee Morning event, students could experience being part of a community of (vocational) practice and being a professional care provider (professional identity).

### **Brief description of curriculum unit 1 as intended: The Coffee Morning**

In the final design of the Coffee Morning unit, the four parameters are manifested in learning and instructional activities as follows. *Shared learning* is incorporated while maintaining the regular division of students in small groups into simulated workplaces (i.e., Welfare and Housekeeping). The groups are responsible for a specific part of the organisational tasks. The students make the invitations, pick up the elderly people from the service flat, welcome the elderly people to the classroom, set up the tables, and make coffee and arrange cake. In addition, each group talks with a group of elderly people about their specific simulated workplace and undertake two activities with the elderly. The students decide on one activity, and the other activity is required as part of the regular curriculum. By requiring the students to participate in these activities, the group identity and the shared goals of the small group are emphasised.

*Meaningful learning* is promoted by having the students know from the start of the project that they would engage in activities with 'real' elderly people. As a result, the preparatory lessons for the event are more meaningful for the students, because they need to be able to skilfully interact with the elderly in a few weeks. The opportunity for the students to decide on an activity to undertake with the elderly contributes to meaningfulness of the learning.

*Reflective learning* is addressed with the use of a competence card. When the project begins, two weeks into the project, and after the event, the students evaluate how competent they think they are on a competence card created by the teachers. The competencies pertain to the preparatory lessons, the conversation about the workplace, the organisation of the activity they chose, and the obligatory activity. The students add competences that are fundamental to the activity that they plan to undertake with the elderly. Reflection is also encouraged during the evaluation after the Coffee Morning event. In groups, students discuss their impressions of the event, what they would do differently, and what they learned. The groups present the results from their evaluations to each other.

*A focus on transferable learning outcomes* is promoted by the organisational composition of the curriculum unit. The students are presented with situations that are increasingly complex. What students learned in the training situation (simulation with classmates) should be applied when they interact with the elderly people during the Coffee Morning event. Learning for transfer is also promoted by conducting a single activity in different ways to show why one way may work better than others. For example, students may find that serving coffee or cake along the left side of a person might cause students to elbow guests in the face.

### **Evaluation of the Coffee Morning unit**

#### ***Evaluation of the design process***

How did the teachers collaborate with the school leader and researchers while developing the curriculum units? We concluded that during the design cycle of the Coffee Morning unit, the teachers and researchers did not share the goal of fostering communities of learners for

vocational orientation for students. Whereas the researchers' aim was on realising the design parameters, the teachers were mostly concerned with organising a new and interesting activity for the students. The researcher, after assuming an attitude of expectation, supported the teachers in the design process by providing a theoretical background for learning in communities of learners and practical suggestions regarding how to incorporate the parameters into the curriculum unit and materials. Still, the teachers considered the parameters of the community of learners for vocational orientation to be the researcher's concern. To guarantee the research aims and guide the design process, the researcher noted that during the joint design of the next curriculum unit, the teachers should address the learning goals and the parameters earlier in the process.

During the joint meetings, the school leader encouraged the teachers to reflect on the choices made during the design process by asking reflective questions. Accordingly, he encouraged the teachers to reflect on the link between the schools' vision regarding teaching and learning and the way this vision was operationalised in the curriculum unit. Although the teachers themselves requested the meetings with the school leader and the researchers, they showed resistance when they found that the meetings focused on why the activities were performed rather than on practical issues related to the activities. Explicit reflection on their own behaviours, choices, and motives was not a common activity for the teachers, although they stated that they 'reflected all day long' (i.e., engaged in implicit reflection).

In sum, the teachers, school leader, and researchers all contributed to the development of the Coffee Morning unit. However, despite the efforts of the school leader and researchers, the parameters of a community of learners only had limited meaning for the teachers. Furthermore, encouraging the teachers to focus on their own learning processes led to resistance.

### ***Evaluation of the implemented curriculum unit***

The second research question, 'Did the implemented Coffee Morning unit promote student learning in the intended shared, meaningful, reflective, and transfer-oriented way?', is answered for each parameter.

The division of tasks aimed to promote *shared learning*. However, because the teachers were in charge of allocating and coordinating the tasks, the groups of students did not need to engage in joint discussions, provide each other with feedback, or work together as classmates. The students knew what to do in their group but knew little about what other groups were doing. As a consequence, the activities that should have promoted shared learning were often not performed as intended. The students worked on the worksheets independently, did not read them properly, and consequently did not follow the steps delineated on the worksheets. Because of the teachers' lack of ownership in designing the worksheets, they did not know how to guide the students in completing the worksheets. Thus, it was concluded that in the next curriculum unit the teachers should know the content and procedures presented on the worksheets by participating in designing the worksheets and that they should pay more attention to realizing positive interdependence between the students.

Working with 'real' people was intended to foster *meaningful learning*. The activities, however, only became meaningful halfway through the curriculum unit, when the event was approaching. During the preparatory lessons, the students received little information about elderly people and how they live, which made it difficult for the students to empathise with their target group. Moreover, the students were not matched to one specific person whom they could focus on, learn more about, and feel responsible for. During the event, it became clear that most of the elderly people were very bright and in good health. Because this specific group of people was quite different from what the students had learned about during the lessons, the students could not fully apply the competences they had practiced. The activities that the students selected to

do with the elderly proved to be meaningful for the students but did not always fit the needs or desires of the elderly. Thus, in the next series of lessons, it was concluded that efforts should be made to acquaint the students with the characteristics of their guests and the person they would be responsible for early in the project and to link the content of the preparatory lessons with the characteristics of these guests.

Although the students completed the competence card properly, most students did so at the request of the teacher rather than because they wanted to *reflect* on what they had learned. During the joint evaluation after the Coffee Morning event, it became clear that the students were aware of what they and their classmates did and did not do well with the elderly guests, although some students found it difficult to provide constructive feedback to one another. Additionally, the students mentioned the feedback they had received from the elderly guests. The students' reflection was most evident in their presentation of their evaluations. Most noteworthy from these presentations was the change in student perceptions of working with elderly people from 'boring' to 'pleasant'. It was concluded that reflection should be made meaningful for the students, for instance, through presenting what they learned. Moreover, explicit direction should be given regarding providing constructive feedback.

*Learning for transfer* was promoted by the increasing complexity of the activity (practicing from a worksheet, simulating the experience through role playing, and actually participating in the event). During these phases, instruction also addressed *why* activities should be undertaken in a particular way. The students, however, did not experience increasing complexity through this design. The students did not perform the role playing seriously until the teacher noted the purpose of the simulation. Moreover, the worksheets that addressed the purpose of the activities were not always followed as intended by the students. These observations show the importance of the teacher's role in encouraging learning for transfer during the lessons. When the teacher explained the purpose of the activities, reflection occurred in a self-evident way. It was concluded that students should be informed about the purpose of the different elements of the lessons during the next curriculum unit and that the purpose of activities should also be made explicit during the lessons.

### **Design process of curriculum unit 2: The Activity Morning**

During the second part of the school year, the same teachers, researchers, and school leader designed another curriculum unit, the 'Activity Morning'. Findings from the experiences in designing the Coffee Morning unit were applied to this new design.

#### ***Step 1: Creating a rough plan***

The teachers proposed presenting activities in a primary school to give students the opportunity to gain experience with another relevant Care and Welfare target group, school children. Similar to the Coffee Morning unit design process, the teachers started to focus on the different organisational aspects of the project (which site, which age group) and how the new curriculum unit would relate to the regular curriculum. The teachers were inspired by a study day on cooperative learning structures in their school and wanted to incorporate these structures into the design. Because the researcher and teachers concluded in evaluating the Coffee Morning unit that the learning goals and parameters should be addressed earlier in the design process, the researcher started to steer the process by explicitly linking the teachers' plans to the goals of the research project. Because integrating the Coffee Morning unit into a regular workplace was complicated, the teachers decided to design an isolated curriculum unit for this project. The researcher did not advocate for abandoning the regular workplace structure, because this learning environment offers the opportunity to shape the learning for transfer parameter, and anticipated that an isolated curriculum unit would not be a lasting part of the curriculum.

The teachers, however, persisted in viewing the regular workplaces as an element separate from the Activity Morning unit. The school leader provided support regarding organisational issues and the design itself. He suggested a primary school and proposed a circulation system for the different activities during the event at the primary school site. Moreover, he asked the teachers to present their experiences with the Coffee Morning unit to the school team, with a focus on the elements that promoted meaningful learning, authentic learning, and learning for transfer.

***Step 2: Elaborating learning goals, learning content, and learning activities and assessing students' learning outcomes***

The researcher proposed creating a lesson plan that included the following elements: learning goals, learning content, lesson composition, instructional methods, materials, lesson conclusion, and parameters of a community of learners for vocational orientation. Her aim was to structure the design process to facilitate the replication of the design at another time or by other teachers. The teachers supported this idea and decided to work out this lesson plan in the five weeks before the curriculum unit was implemented. On the researcher's initiative, the teachers discussed which of the examination regulations were relevant to address in the curriculum unit. The teachers also discussed which learning goals they thought were important to the students. They discussed what students had to learn to work with primary school children; however, how the various learning goals related to each other was not evident to the teachers. The teachers discussed what curriculum content should be addressed each week to prepare the students for the event. For each learning activity, an instructional method was designed. The researcher and the teachers used the materials from the study day on cooperative learning structures to create learning activities and were inspired to develop their own structures. The school leader followed the design process, asking the teachers to report what they had already designed and their further plans. He also provided input on the design and actively participated in preparing the presentation for the school team.

***Step 3: Checking the four design parameters***

The teachers, supported by the researcher, thoroughly prepared the first lessons of the curriculum unit. However, the teachers found it difficult to work systematically and translate the abstract parameters of a community of learners into learning activities. Working out the cooperative learning structures was more difficult than expected. Finally, only two weeks were left to create the lesson materials. While implementing the first week's lessons, the design hours were used to discuss how the upcoming weeks' learning activities should be performed. Time pressure made it even more difficult for the teachers to think about how to incorporate the parameters of a community of learners into the design; again, the researcher posed questions to the teachers about the extent to which the parameters were incorporated in the design and made suggestions for improvements. The school leader was involved in the planning process and deciding on the design content during the joint meetings and helped emphasise the link between the school's vision and the parameters.

**Brief description of curriculum unit 2 as intended: The Activity Morning**

In the design of the Activity Morning unit, the parameters of a community of learners for vocational orientation are manifested in learning and instructional activities as follows. *Shared learning* is promoted by grouping the students and asking each group to present an activity on a worksheet that can be executed by all the groups with the primary school children during the event. This particular activity is organised to promote positive interdependence, a basic element of cooperative learning (Kagan, 1994). Far more than during the Coffee Morning unit, the

students are encouraged to make plans together, deliberate, supplement each other's ideas, and provide feedback to each other. More than during the Coffee Morning unit, cooperative learning structures are incorporated into the unit to structure the interactions between the students.

*Meaningful learning* is realised in the design by telling the students when the lessons begin that they will organise an event for children at a primary school. The students are shown a video that contains impressions of the particular school, the teachers, and the children in grades 1 and 2. The groups also are assigned 'their' children, which allows the students to adopt the role of a primary school teacher, learn about the children, and feel responsible for successfully carrying out an event at the school. The opportunity for the students to decide on activities to undertake with the children also aims to encourage meaningful learning. The teachers provide guidelines for these activities. The class then decides which of the proposed activities to perform at the primary school.

*Reflective learning* is stimulated by asking students to provide feedback on each other's activities concerning the activity's suitability for the children, the clarity of the steps of the activity, and the necessary materials. This feedback is used to make a final version of each worksheet. Moreover, the students reflect on the competences that they should develop to present the event properly, using the Think, Pair, Share strategy (Kagan, 1994). The activity aims to encourage the students to reflect on whether working with children suits them and on the necessary knowledge, skills, and professional attitude for this work.

A focus on *transferable learning outcomes* is promoted by the organisation of the series of lessons. The activities are practiced by role playing with classmates and are later performed with the primary school children. During the curriculum unit, the teachers constantly note the reasons why the activities should be done in a certain way.

## **Evaluation of the Activity Morning Unit**

### ***Evaluation of the design process***

How did the teachers collaborate with the school leader and researchers in developing curriculum units that would foster communities of learners for vocational orientation? The researcher encouraged the teachers to work systematically by creating a lesson plan and focusing on the learning goals and incorporating the parameters for communities of learners earlier in the design process. Although the researcher's guidance did structure the teachers' activities at the beginning of the design period, when they started feeling time pressure, they eventually abandoned this plan. Moreover, during the Activity Morning design process, the teachers and the researcher still did not share the goal of designing learning environments that foster a community of learners for vocational orientation. Addressing the parameters in the design was the researcher's goal, and this remained her task. This goal was clearly less meaningful to the teachers. The teachers easily discarded elements of the design that reflected the community of learners concept, even after experiencing the value of the elements during the Coffee Morning unit. The teachers' main aim remained designing activities that the students would enjoy. The researcher's evaluations with the teachers after implementing the Activity Morning unit presented a proper moment for the teachers to reflect on the designed curriculum unit and the process of designing the unit. Nevertheless, they indicated that the evaluations were of more interest to the researcher than to themselves.

The school leader tried to encourage the teachers to reflect on their design activities for the Activity Morning unit during the joint meetings. By asking the teachers to present the Coffee Morning unit to the team, he provided the teachers with an audience (meaningful context) to present their work as a good practice, and he encouraged the teachers to reflect on the process

because preparing the presentation required thorough reflection. For the teachers, however, the presentation concerned only an accidental circumstance that demanded substantial time. Although the presentation provided an opportunity for shared, meaningful, and reflective learning for the teachers, they did not appreciate the value of this opportunity. The presentation of the Coffee Morning unit was more meaningful to the school leader than to the teachers. In sum, regarding the first research question (concerning the process of developing curriculum units), we concluded that the input and structure that the researcher provided during the Activity Morning design process did not substantially affect how the teachers designed the activities or how they approached designing the activities. Moreover, we concluded that the researcher's and school leader's actions did not fundamentally affect how the teachers viewed the parameters of a community of learners for vocational orientation. The teachers were not focused on their own learning processes, no matter how explicitly the researcher and the school leader attempted to facilitate their learning.

### ***Evaluation of the implemented curriculum unit***

We now discuss the second research question, 'Did the implemented Activity Morning unit promote student learning in the intended shared, meaningful, reflective, and transfer-oriented way?', for each parameter.

*Shared learning* was promoted using principles of cooperative learning. The students created an activity on a worksheet for the rest of their classmates, and the class selected activities that seemed suitable for the primary school children; however, because of a lack of time, the theoretical knowledge that the students' learned was not applied to the selected activities. As a result, an exchange of information between students did not occur. We concluded that although the design of the curriculum unit did incorporate principles of cooperative learning to promote shared learning, the shared learning of the students was different from what was intended.

*Meaningful learning* was promoted via the video clips of the primary school children in their school and the freedom the students were given to select their own activity to undertake with the children. The students were enthusiastic about and interested in the video clips of the children ('Boy, they are active!'), whereas they were less interested in the clips of the primary school environment. As a result, the students developed an image of the target group but were not able to get an idea of the opportunities that the primary school environment offered for possible activities. The teachers concluded that they would guide the students through the video clips next time (e.g., by making remarks such as 'Look, there is a small stage that you may use for activities'). The students appreciated the freedom to choose activities, even though the activities had to meet certain criteria. Giving the teachers less control and the students more control over the activities is a learning point for designing future curriculum units.

*Reflective learning* was expected to occur, as the students gave feedback on the worksheets of other groups and the other groups' competences. Some of the groups, however, did not revise their worksheet on basis of the received feedback. The worksheets did not seem important to the students during the event because they had already spent so much time discussing one another's activities. Student competence was strongly improved in the Activity Morning unit compared with the Coffee Morning unit. Because the students had to think about which competences they had to develop for the event, more reflection occurred. Still, the students found it difficult to convince their classmates of their own competences. They did not clearly appear to think about whether working with children would suit them. It was concluded that the design of future curriculum units should focus on the following aspects: providing more freedom concerning how the students should utilise feedback, stimulating reflection by letting the students think about the competences they need to develop, and carrying out the unit with a focus on the event itself rather than 'working with children' in general.

The focus on *transferable learning* outcomes was grounded in the organisational composition pertaining to selecting activities, practicing with classmates, and executing the activity with the target group, followed by an evaluation. The students handled themselves well at the school site during the event and interacted properly with the children. Still, the students were not continually oriented to the tasks of selecting activities and practicing with their classmates during the lessons, as they thought they would manage fine without preparation. We concluded that the design of future curriculum units should focus on the following aspects: elaborating on the proper application of instructional methods in the context of practicing activities with classmates, involving students more in preparing for the event, and providing examples of situations in which performing activities would be more difficult (for example, role playing in which they have to deal with shy or hyperactive children).

## 6. Discussion

In this chapter, we examined how researchers, teachers, and a school leader designed and implemented a learning environment aimed at fostering a community of learners in pre-vocational education, using a conceptual framework consisting of four parameters (shared, meaningful, reflective, and transfer-oriented learning) as a point of departure. Two curriculum units were developed and implemented: the Coffee Morning unit and the Activity Morning unit. Our research questions focused on the way the teachers collaborated with the school leader and researchers during the process of developing curriculum units and on whether the implemented curriculum units promoted student learning as intended.

Regarding the first question, we conclude that teachers were actively involved in the process of designing and implementing the curriculum units. Nevertheless, the teachers did not appreciate the value of the community of learners for vocational orientation. During both design cycles, the teachers paid considerable attention to the organisational aspects of the units (who, what, where, and when). Moreover, they only focused on learning goals, learning content, instructional methods, and assessments, after the organisational matters were settled. Keeping the teachers focused on the parameters of a community of learners for vocational orientation remained the responsibility of the researcher. Relating the parameters and the developed curriculum units to the school's vision regarding teaching and learning and reflecting on possibilities for transferring the lessons learned to other curriculum units only occurred when the school leader encouraged such reflection.

In retrospect, we can wonder whether the participants truly had a shared goal in this design research. Although the teachers, the school leader, and the researcher agreed to collaborate in fostering communities of learners for vocational orientation, they each pursued their own goals. For the teachers, the main focus was on designing activities that the students would enjoy, while the school leader's focus concerned school development and disseminating innovative learning practices in the school, and the researcher was interested in investigating the use of communities of learners to enhance students' quality of and engagement in learning. Realising so many different goals at such different levels may have been too ambitious for a two-year project. Additionally, because the researcher, who developed the idea of fostering communities of learners, initiated the project, teachers' appreciation of the communities of learners concept had to be developed during the process. Finally, the collaboration method used in the design research was not a regular practice in the school. As a result, the teachers did not reflect on the process together (make plans, provide colleagues with feedback, and reflect on how what they were doing was in line with the school's vision regarding teaching and learning). We believe that these problems would be typical of collaborations between researchers, teachers, and school leaders but that being more explicit about the roles expected from the

participants and allowing more time for the design process may mitigate some of these issues. Participating in a design research study requires more than teachers' motivation to participate. Researchers should be aware that structured and conceptual reasoning are academic skills that are not self-evidently developed by teachers. It seems advisable to help teachers to draw on and develop these skills. Additionally, time is needed to develop a shared conception of the starting points for developing curriculum units. A fruitful design process is only possible when these starting points fit the school's vision and when that vision is elaborated and applied by not only the school leader but also the individual teachers involved. In addition, engaging teachers in the context and problem analysis phase of a design research study, i.e., the first instead of the third phase, may help the development team to arrive at a shared conception of the goals of and the starting points for developing curriculum units.

Regarding our second research question, we conclude that with the second curriculum unit (Activity Morning), we were better able to promote student learning as intended than with the first (Coffee Morning). The parameters were better manifested in the design of the Activity Morning unit than in that of the Coffee Morning unit. Shared learning, for example, was more clearly present because approved cooperative learning instructional methods were incorporated in the design. Regarding meaningful learning, the design allowed the students to gain a much better understanding of the target group (primary school children), thus facilitating the students' ability to assume the professional role of a primary school teacher assistant. In the second unit, having the students think in advance about which competencies they would have to develop for the event and use this information for reflection afterward made the reflection on what was learned more meaningful to the students.

All evaluations during the design research study yielded new suggestions for improvement. For example, a tentative heuristic for meaningful learning, derived from the conceptual framework, was to 'have students participate in an authentic ('real') vocational activity'. This tentative heuristic was incorporated in the design of the Coffee Morning unit by having students prepare for and eventually accompany and support elderly people during diversional activities. As this did engage students in meaningful learning during the event with the elderly, but not during the preparatory lessons, we adjusted the heuristic to 'help student understand how to prepare for and establish an authentic vocational activity'. This heuristic was subsequently incorporated in the Activity Morning unit by introducing the school children to the students at the start of the unit. This design increased the students' meaningful learning, but as the teachers largely controlled the preparatory lessons, the students were unable to effectively adopt the professional role of a primary school teacher assistant. Therefore, the heuristic was adjusted once again to 'help students understand how to prepare for and establish an authentic vocational activity and take the lead in doing so'. Thus, the collaboration with the teachers and school leader enabled us as researchers to refine and elaborate the tentative heuristics that we started out with.

In conclusion, despite the challenges we encountered, we believe that we were able to elaborate the community of learners concept in a way that is useful for prevocational secondary education. The collaboration between researcher, teachers, and a school leader resulted in ecologically valid designs and elaborated heuristics. Additionally, the curriculum units appeared effective in enhancing students' quality of learning and engagement (we report on this summative evaluation elsewhere: Boersma, Ten Dam, Wardekker, & Volman, in preparation). Although we are uncertain of the extent to which the community of learners concept and the parameters were meaningful to the teachers, several years after our design research, the effects of the project appear to have taken root in the school. The success of the curriculum



units developed in the context of our design research motivated the teachers to continue these kinds of projects. The Coffee Morning and Activity Morning have become part of the regular curriculum of the school, and similar units for the 10<sup>th</sup> grade curriculum were developed and implemented by the teachers.

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## Integrating Disciplinary Literacy into Middle-school and Pre-service Teacher Education

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# 23. Integrating disciplinary literacy into middle-school and pre-service teacher education

Jamie Colwell & David Reinking

## Abstract

*This case describes a summary of a formative experiment, a framework specific to educational design research, simultaneously conducted in a middle-school history classroom and a university social studies methods course. The purpose of the study was to refine an intervention to promote disciplinary literacy in history. The intervention provided middle-school students and pre-service teachers with explicit strategies to promote disciplinary literacy, while participating in a collaborative blog project engaging them in disciplinary literacy. Conclusions suggest practical consideration for implementation of disciplinary literacy into history. The case outlines the five phases of the formative experiment and briefly overviews modifications made during the intervention. Further, it offers suggestions and considerations for employing this approach to research.*

## 1. Introduction to the problem

Becoming literate entails much more than learning to decode the alphabetic code of written texts, which is typically the main focus of initial reading instruction. For example, educators have a responsibility to help students meet the demands of reading, interpreting, and evaluating academic texts in the context of the increasingly specialized courses and content that students encounter as they progress through their years in school. But, where exactly does the responsibility fall for developing the skills, strategies, and dispositions needed for successful reading of academic texts in middle and secondary grades, particularly developing a critically evaluative stance? Should English Language Arts teachers teach students generic strategies that apply generally to all subject areas such as mathematics, history, and science? Or, because the texts and their function in each subject area are unique, should teachers of specific subjects be charged with helping students become literate in the domain of their respective subject area? How can teachers in middle schools and secondary schools integrate literacy in their subject area in a way that reinforces, or is at least is not distracting to, the content they are most interested in teaching students? And, how can effective strategies for doing so be communicated to and practiced by pre-service service teachers preparing to become teachers in a particular subject area?

Literacy researchers and educators have long struggled with these questions (e.g., O'Brien & Stewart, 1990; O'Brien, Stewart, & Moje, 1995; Ratekin, Simpson, Alvermann, & Dishner, 1985; Stewart & O'Brien, 1989). Beginning in the late 1990s, a new focus on adolescent literacy emerged in the field (Alvermann, 2002; Jetton & Dole, 2002; Moore, Bean, Birdyshaw, & Rycik, 1999) and along with it a new perspective referred to as *disciplinary literacy*, which influenced a response to these questions (Juel, Hebard, Haubner, & Moran, 2010; Moje, 2008; 2010/2011; Shanahan & Shanahan, 2008; Wilson, 2011). In a nutshell, disciplinary literacy is the concept that literacy skills in each content area are specific to the unique learning objectives of a discipline. For example, in social studies, particularly the area of history, disciplinary literacy implies instruction grounded in investigating, comparing, and contextualizing texts about

historical events. Such a stance leads readers to draw conclusions and interpret those events, which may contribute to developing a democratic perspective and informed citizenship, both of which are goals of social studies education (Mosborg, 2002).

Yet, despite considerable theoretical speculation about disciplinary literacy, there have been few attempts to investigate the viability of applying that perspective in classrooms and how it might be feasibly incorporated into the preparation of pre-service teachers. We believe design-based research, specifically what has been called a formative experiment (Reinking & Bradley, 2008; Reinking & Watkins, 2000), an example of which we report here, addresses that limitation, because it is well suited to determining whether such theoretical perspectives hold up in authentic classroom practice and how they can be workably implemented. A formative experiment falls under the general umbrella of design-based and educational design research (Reinking & Bradley, 2008), and aims to develop usable interventions that may be implemented in authentic classroom contexts. Thus, our goal was to implement and to refine, as needed, an intervention designed to instantiate the concept of disciplinary literacy in a middle-school social studies classroom and simultaneously in a social studies methods course in a university program for pre-service teachers. The central feature of the intervention enabled middle-school students and pre-service teachers to discuss history texts by posting and responding to an online blog. We aimed to refine instructional methods and a type of online writing activity that may be continued in the middle-school classroom following the conclusion of the study. We justified using a formative experiment because this approach is especially appropriate for investigating how promising interventions might be implemented to accomplish valued, and often difficult-to-achieve pedagogical goals that imply transformations of instructional orientations and practices. Further, formative experiments are conducted to align theory, research, and practice by designing interventions in authentic contexts (Reinking & Bradley, 2008).

In the remainder of this chapter we summarize briefly a recently completed study. Soon, we intend to submit a more detailed report of our findings for publication. We overview our methodological framework, describe the intervention and its theoretical basis, summarize a few preliminary findings and conclusions, and reflect on what we learned about disciplinary literacy and about our methodological approach.

## 2. The study

A formative experiment focuses on implementing workable interventions in classrooms, on testing, developing, and refining theory, and on generating design principles for a particular intervention. This approach has been used frequently to investigate instructional interventions pertaining to literacy. For example, formative experiments have been published regularly in *Reading Research Quarterly*, the field's leading, most rigorously reviewed journal (e.g., Ivey & Broadus 2005; Jimenez, 1997; Neuman, 1999; Reinking & Watkins, 2000). In this section we overview the framework we employed using this approach; we identify the two complementary pedagogical goals guiding the study; we specify the five distinct phases of the study; and we describe the intervention.

### Framework

The framework of our study followed Reinking and Bradley's (2008) six guiding questions for a formative experiment:

1. What is the pedagogical goal to be investigated and why is that goal important?
2. What is an intervention that has potential to achieve the pedagogical goal and what is the theoretical and empirical support for that potential?



3. What factors, based on data collection and iterative analysis, enhance or inhibit the intervention's effectiveness, efficiency, and appeal?
4. How can the intervention be modified in light of these factors?
5. What unanticipated positive or negative outcomes does the intervention produce?
6. Has the instructional environment changed or been transformed as a result of the intervention?

### **Phases**

We conducted this study in five phases: (a) recruitment of participants, (b) characterization of the instructional environment, (c) collection of baseline data, (d) iterative collection and analyses of data during the intervention, and (e) retrospective analysis. These phases are described with our findings in a subsequent section.

### **Goal**

Unlike a typical formative experiment, our investigation had two complementary goals for two distinct but related populations, rather than a single goal for one population:

**Goal 1:** Improve eighth-grade social studies students' use of disciplinary literacy in history, specifically improving their abilities to make connections with text, question the author/text, and draw conclusions based on evidence, through discipline-specific strategy instruction and collaborative blog discussions about history texts.

**Goal 2:** Improve pre-service teachers' use and understanding of instructional techniques beneficial to improving middle-school students' disciplinary literacy skills, specifically using strategies that improve students' abilities to make connections with text, question the author/text, and draw conclusions based on evidence, through collaborative blog discussions with students about history texts.

### **The intervention**

The object of a formative experiment is to investigate an intervention that can be justified as having potential to address the pedagogical goal. An intervention is defined by its essential elements, which we believe should be explicitly identified. Essential elements remain even when the manner, timing, and conditions for implementing them vary in response to data suggesting useful or needed modifications. These elements are selected while designing the intervention based on a review of literature and theory. Similar to the components of Van den Akker's (2003) curricular spiderweb, essential elements are fundamental to the rationale for the intervention's previous or potential success in accomplishing the pedagogical goal and provide a consistency and coherence to the design of the intervention, even when modifications are made. Interventions and their essential elements are analogous to building a bridge. To design a bridge, an engineer will take into consideration a particular site, anticipated purposes of the bridge, available materials, budget restrictions, and so forth. In light of those considerations a designer will first choose a basic structural approach, or a combination of several approaches, such as arch, cantilever, truss, suspension, and so forth. Each of these approaches has invariant defining elements that must be present to be true to the basic design, although they each may be developed and applied in countless variations. In the present investigation the essential elements defining the intervention and selected to achieve the goals were as follows: (a) middle-school students in a social studies class posting reactions to their reading of historical texts on a personal blog, (b) pre-service teachers in a social studies methods course reading and responding directly to middle-students about their blog postings, (c) integrating

strategies consistent with disciplinary literacy into middle-school students' and pre-service teachers' instruction.

More specifically, eighth-grade students wrote blog posts reacting to primary and secondary texts they were assigned to read on topics in their regular social studies class. The class focused on the history of South Carolina, and the texts followed events in South Carolina history as specified by the state curriculum. Pre-service teachers in a social studies methods course at a local university were paired with the middle-school students and responded to the blog postings by posting reactions, questions, and prompts that would encourage further thought about the topic. The researchers and a middle-school social studies teacher collaborated to develop and integrate accompanying disciplinary-literacy strategies into the teacher's existing curriculum. These strategies included activities focusing on making connections between texts and prior knowledge, using Questioning the Author (QtA), a reading strategy for analyzing text, (Beck, McKeown, Sandora, Kucan, & Worth, 1996), and drawing conclusions based on evidence (DECIDE, a critical thinking strategy that Beyer, 2008 developed for use in social studies instruction). These strategies were also presented, practiced, and discussed with the pre-service teachers in their social studies methods course during their regular class periods. Anchored by the blogging activity, these strategies were introduced as examples of integrating disciplinary literacy into social studies instruction.

New readings in conjunction with the social studies topics were introduced and assigned every other week, with a blog posting required in the first week and a response to the posting from the university student in the subsequent week. University students read the texts along with the students. Each reading was purposefully short (5-7 paragraphs) to increase the likelihood that students would focus on reading critically and not be distracted by a lengthy reading assignment. A new reading was introduced every other week with the middle-school students reading the assigned texts and writing a reaction on their blog during the first week, and the university students responding during the second week. Each bi-weekly topic became an iterative cycle for making modifications to the intervention based on data collection and analysis during the previous cycle.

### **3. Theoretical and empirical base for the intervention**

The justification for the intervention and its essential components is drawn from the literature related to disciplinary literacy in middle-school history and to pre-service social studies teacher education. That literature is briefly reviewed in this section.

#### **Disciplinary literacy in middle-school history**

The first pedagogical goal targeting the middle-school setting in the intervention investigated in this study was to improve students' use of disciplinary literacy through strategy instruction and blogging. The rationale for that goal is that most adolescent students are lacking in strategies that evaluate information across textual sources to form overall interpretations (Afflerbach & VanSledright, 2001; Barton & Levstik, 2004; Hynd, Holschuh, & Hubbard, 2004; Stahl & Shanahan, 2004) and that blogging may extend critical thinking beyond the walls of the classroom (Black, 2005; McDuffie & Slavit, 2003), supporting critical reflection and construction of new knowledge. Further, disciplinary literacy, as a theoretical perspective, suggests that different purposes for reading in different content areas require different literacy skills, strategies, and dispositions (Moje, 2008; Shanahan & Shanahan, 2008). A formative experiment offered the opportunity to work with a social studies teacher and her students to understand how disciplinary literacy might be integrated into an authentic classroom. Further, the present formative experiment sought to expand the literature regarding how disciplinary literacy may be realistically incorporated into a middle-school classroom.

### **Disciplinary literacy in pre-service social studies teacher education**

The second goal of the intervention targeted improving pre-service social studies teachers' use and understanding of disciplinary-literacy instructional techniques. This goal was guided by research suggesting a resistance to literacy instruction among middle school and secondary teachers (Moje, 2008; O'Brien & Stewart, 1990; O'Brien, Stewart, & Moje, 1995; Ratekin, Simpson, Alvermann, & Dishner, 1985). Even when researchers and educators provide useful instructional strategies in teacher education and professional development, many teachers are not willing to devote time to implement content literacy strategies into their curricula (Greenleaf, Schoenbach, Cziko, & Mueller, 2001; Hall, 2005; O'Brien et al., 1995), suggesting that further action is necessary to prepare pre-service teachers and teachers to integrate literacy into instruction. A logical step in this preparation may be working with pre-service teachers and their instructor to integrate disciplinary literacy instruction that is appealing to the pre-service teachers and complementary to the goals of a social studies methods course (Nokes, 2010). A formative experiment, which provides flexibility to adapt the intervention to complement the course objectives, provided an opportunity to study how disciplinary literacy may be integrated into the methods course and add to local theory concerning disciplinary literacy and pre-service social studies teacher education.

## **4. Summary of methods and findings**

In this section we summarize our methods and report a few preliminary findings. We organize our summary to correspond with the five phases of our investigation: recruitment of participants, characterization of the instructional environment, collection of baseline data, iterative collection and analyses of data during the intervention, and retrospective analysis.

### **Phases 1 and 2: Recruiting participants and characterizing the instructional environment**

Reinking and Bradley (2008) suggested that in most instances an initial formative experiment to investigate a promising intervention should avoid being conducted in an environment where success or failure is almost assured. Thus, for the purposes of the present investigation, we selected a middle-school class with average student achievement in social studies. Likewise, we sought a teacher and a university instructor who were supportive of our goals, but who were not already systematically implementing instruction to achieve them. We used these criteria in purposive sampling (Patton, 2002) to consider contexts and participants as candidates for participation.

After pursuing several possibilities during the spring preceding the study, we recruited the participation of a middle-school eighth-grade state history class located in a rural school district in South Carolina. The class had 25 students and a teacher who had 13 years' experience in teaching middle-school social studies. We held two meetings with the teacher, Ms. Wells (all names are pseudonyms) in the summer to discuss and plan implementation of the intervention into her class instruction. Although supportive of increasing her students' critical reading of relevant documents and texts pertaining to state history, she was not explicitly integrating that perspective into her teaching before the study. Ms. Wells held a bachelor's degree in social studies education and master's degree in administration. The class consisted of 13 girls and 12 boys. Seven students were African American, 13 students were Caucasian, and five students were Hispanic. No student was classified as learning disabled or received special education services.

In the summer preceding the study, we recruited a professor and 28 undergraduate pre-service teachers in a social studies education program, which prepared them to be social studies teachers. The professor, Dr. Nelson, held a Ph.D. in social studies education and was an adjunct professor, and we also met with Dr. Nelson during the summer to plan instruction. The

class consisted of 14 females and 14 males of which 25 were classified as Caucasian and three as African American. All pre-service teachers were in good academic standing, but none were enrolled in the honors college.

To better understand these contexts prior to implementing the intervention qualitative data including structured field notes, video/audio recordings, semi-structured interviews, and participant interviews were collected during the two weeks immediately preceding the start of the intervention. These data were analyzed to build rich, elaborated descriptions of each setting (Merriam, 1998) to characterize the context of the settings, which enabled us to better understand if and how the settings were transformed during the intervention.

### **Phase 3: Establishing a baseline**

The qualitative data collected in Phase 2, and used to characterize the instructional environments, also contributed to establishing a baseline to compare and determine transformations in the instructional environments. Analysis of these data suggested that Ms. Wells' instructional style prior to the intervention was teacher-centered with most activities involving lecture and students searching for specific answers to end-of-chapter and workbook questions in their textbooks. Data also suggested that, prior to the intervention, Dr. Nelson primarily utilized lecture and small group activities during instruction, and instruction focused on inquiry-based teaching methods.

However, in Phase 3, we also gathered data to establish participants' status in relation to the specific components of disciplinary literacy addressed in the pedagogical goals. That data would be a baseline against which we could assess progress formatively during and at the end of the subsequent intervention phase.

One week prior to implementing the intervention, qualitative data were collected using a Strategic Content Literacy Assessment (SCLA) to determine middle-school students' disciplinary literacy skills and pre-service teachers' use of disciplinary-literacy instructional techniques (Alvermann, Gillis, & Phelps, 2012). An SCLA is an informal reading assessment adapted from Brownlie, Feniak, and Schnellert's (2006) Strategic Reading Assessment, which focuses on generic reading practices. The SCLA is a type of assessment with clearly articulated curriculum targets to provide feedback on what and how students learn. Teachers can customize it to assess literacy strategies and skills specific to any content area. An SCLA specific to history was developed independently for each group. The middle-school version assessed the targeted disciplinary-literacy components addressed in the first pedagogical goal of the intervention: (a) making connections between personal and prior knowledge with texts, (b) questioning authors or texts, and (c) drawing conclusions based on evidence. The version for the pre-service teachers provided data about how they viewed and approached disciplinary literacy instruction in areas relevant to the intervention, such as (a) helping students to make connections between personal and prior knowledge and text, (b) helping students to question the author and text, and (c) helping students to draw conclusions based on evidence.

Results from the SCLA indicated the middle-school classroom presented a range of the skills, strategies, and dispositions relative to the pedagogical goal, although overall students' responses indicated an opportunity for improvement. For example, most of the middle-school students in this study could form connections between texts or prior knowledge. However, fewer students could appropriately question the author and validity of the text, and almost none of the students were able to draw a conclusion based on evidence. Baseline pre-service teacher SCLA evaluations indicated that pre-service teachers were able to describe general instructional techniques to encourage disciplinary literacy, but most were unable to indicate specific examples of those techniques or how those techniques might be implemented instructionally. These data reinforced our decision to implement explicit strategy instruction in

the intervention with focus on structuring middle-school students' consideration of the validity of the author/text and drawing conclusions based on evidence. We hypothesized that these strategies would also provide pre-service teachers with concrete methods to provide disciplinary-literacy instruction.

**Phase 4: Implementing the intervention and making modifications**

The intervention was integrated into instruction for 11 weeks, as described in a previous section, and was organized around five topics, each requiring approximately two weeks (see Table 1). During the intervention phase we collected data aimed mainly at answering questions three and four in the framework for our study, as described in a previous section. However, in this phase we also noted observations that addressed question five concerning unanticipated outcomes and question six concerning any evidence of general transformations in the instructional environment.

To structure data collection, we used an embedded, single-case study (Yin, 2009). The intervention was considered a single-case and the iterative cycles that paralleled the sequential two-week discussion topics focused on the readings were considered embedded units of analysis (Yin, 2009). Consistent with standards of rigor for qualitative research (Creswell, 2007; Yin, 2009), multiple sources of data were collected and analyzed during this phase including: (a) semi-structured interviews with participants, (b) audio/video recordings, (c) structured field notes, (d) informal interviews with participants, (e) pre-, mid-, and post-study SCLAs in both settings, (f) participant observations, and (g) blog postings. These data were collected to understand how the intervention functioned in each of the two settings, reactions to the intervention that might affect its failure or success, and changes in the instructional environments over the course of the intervention. Data were analyzed using constant comparison (Glaser & Strauss, 1967) to determine themes and to thus specifically to suggest enhancing and inhibiting features of the intervention. Three examples of those themes and the modifications they informed follow.

*Table 1: Intervention Topic Schedule*

<b>Weeks</b>	<b>Topical Units</b>
<b>1 &amp; 2</b>	Blog Introductions and English Explorers in the Carolinas
<b>3 &amp; 4</b>	Colonial Women in the Carolinas
<b>5 &amp; 6</b>	Slavery in the South Carolina
<b>7 &amp; 8</b>	Plantation Life in South Carolina
<b>9 &amp; 10</b>	American Revolution in South Carolina
<b>11</b>	Final blog posts to conclude the blog project

**Modification 1:** Changes in the parameters of blogging. This modification illustrates how some of the modifications are likely to be basic logistical issues of implementation associated with the local context, but that may nonetheless have implications for other similar contexts. The initial version of the intervention specified that middle-school students write their blogs responding to the history texts outside of their scheduled class. However, during the first iterative cycle, we

discovered that the blog site students were permitted to access at school was blocked on their home computers as well as at the county library. The technical personnel at the district office were unable to reset filters to accommodate access outside of school. Consequently, we modified the blogging component of the intervention so that middle-school students could visit the computer lab and media center computers during class in small groups. That modification required the teacher to accommodate access during the class period including providing supervision in a nearby computer lab. Initially, this modification produced enhancing affects. For example, students were still required to read and take notes on the history texts outside of class, and Ms. Wells made going to the computer lab, which students enjoyed, contingent on showing the notes taken. These contingencies insured that all students had read and responded to the assigned readings by the assigned time.

This modification produced another positive outcome. It enabled Ms. Wells to see students' enthusiasm for blogging in the computer lab, which, in turn, seemed to encourage her to integrate more digital technology into her classroom and reinforced the potential of the intervention to motivate her students and get them involved with a more in-depth analysis of their reading about historical events. We also noted that Ms. Wells seemed to make a more concentrated effort to connect the ideas students expressed in their blogs to topics they studied as a class. In other words, our attempts to address an initially bothersome technological constraint gave us a new, an potentially useful pedagogical understanding: Creating conditions under which teachers can observe first-hand the motivating effects of blogging may motivate teachers to invest in using technology to promote disciplinary literacy.

**Modification 2:** Strategy instruction. Despite her increased motivation, data analysis during the second iterative cycle indicated Ms. Wells was reluctant to integrate the disciplinary-literacy strategies we planned into her teaching. For example, she would inform us of an upcoming lesson she had planned using a strategy, but on the day one of us visited she would not use the strategy. Based on observational and video data, we determined that Ms. Wells did not use the explicit strategy instruction in her lessons on several occasions as planned during the intervention. We hypothesized that she may be uncomfortable with this type of instruction, which could be an inhibiting factor, which was indirectly supported in our observational notes and interviews. Thus, we scheduled a planning meeting to discuss a different method of integrating the strategy into her instruction. Instead of generally integrating explicit strategies into her instruction as we had originally discussed, we proposed that she provide students with a guide requiring them to locate components of disciplinary literacy in model blog posts that responded to history text with which the students were already familiar.

Ms. Wells enthusiastically agreed with this modification, and almost immediately implemented the revised approach into her instruction. This modification had two complementary positive outcomes. The middle-school students were provided with modeling of disciplinary literacy strategies with which they eagerly engaged and seemed to need. Likewise, their eagerness to engage in more thoughtful reflection on the texts seemed to again boost Ms. Wells' confidence in her students' engagement with disciplinary literacy. Further, the pre-service teachers who were alerted to this modification seemed to benefit from observing this model of reflective reading by becoming more attuned to disciplinary literacy and how it might be integrated into classroom instruction. Thus, for future use of the intervention, we learned that providing a more explicit model of how to reflect on a history text may not only enhance the blogging activity for students' benefit, it may also reinforce their teachers' integration of disciplinary literacy. We also learned that this modification may benefit future teachers' understanding of disciplinary literacy and how they might implement it with their students. Finally, we learned that the concept of disciplinary literacy may need to be more explicitly represented to teachers and through multiple

types of instructional methods if it is to overcome their potential discomfort with integrating it into their instruction.

**Modification 3:** Reflective blog writing. A third modification to the intervention occurred during the third iterative cycle. Data analysis during this and the previous cycle suggested that middle-school students struggled to write reactions to text. Most students only summarized the history readings and used the minimum number of sentences Ms. Wells required for their blog posts. Data revealed students had little previous experience in this class expressing their opinions about texts in history through written reflection. Their difficulty in writing reflective responses made it difficult for the pre-service teachers to respond in ways that might stimulate deeper discussions, although it did reveal to them that they could not necessarily expect their future students to engage easily in reflective writing.

To aid students in writing a more reflective blog posts, we worked with Ms. Wells to develop a guide to writing a reflective blog. The guide consisted of eight questions students should ask themselves as they read and to reflect on after they finished reading. The guide focused on the disciplinary literacy common to historians, which were the focus by the intervention. Students could use these questions and prompts to write their reflections and consider their opinions about the assigned readings. The writing guide improved students' responses and, in turn, improved discussion between middle-school students and pre-service teachers.

We learned that enacting the intervention successfully is likely to entail more explicit prompts for middle-grade students to engage in reflective responses to historical texts. Interestingly, an unanticipated positive finding suggesting a transformation of the instructional environment was that Ms. Wells used this new knowledge about her students to incorporate other reflective writing activities into her teaching. Further, we learned that pre-service teachers might gain insights about middle-school students' capabilities related to disciplinary literacy by corresponding with students who have not been given that support. By extension, we also learned that disciplinary literacy, at least in social studies, may not occur without considerable support for and practice of the skills, strategies, and dispositions that define literacy in a particular discipline, although that conclusion is subject to further research with other interventions in other disciplines with other students.

#### **Phase Five: post-intervention retrospective analysis**

After the intervention was concluded, we conducted a retrospective analysis (Gravemeijer & Cobb, 2006) utilizing all the data we had collected and analyzed formatively during the investigation. The intent was to integrate our findings, drawing conclusions about pedagogical theory and generating pedagogical principles and recommendations that might guide practitioners and future researchers. We focused particularly on the final two questions that comprised the framework for this study: What unanticipated positive or negative outcomes does the intervention produce? Has the instructional environment changed or been transformed as a result of the intervention? The following are some examples of findings from this phase:

**Unanticipated outcomes.** Several notable unanticipated outcomes related to writing emerged from the retrospective analysis. For example, middle-school students' writing spontaneously shifted from an informal style of blog writing at the beginning of the intervention to a formal style by the end of the intervention. Blog writing typically does not follow the formal mechanics of writing (McGrail & Davis, 2011; Utecht, 2007). And, Ms. Wells told students that they had the freedom to use an informal style in their blog posts. However, most pre-service teachers elected to use a formal writing style when blogging, possibly because they perceived their role as that of a teacher who should model formal writing. We found that the middle-school students were

conscious about how they represented themselves in writing to the university students, which seemed to encourage them to gradually mimic the more formal style of the pre-service teachers. Thus, this intervention may promote a heightened awareness of formal writing among middle-school students and contribute to their development of a more academic identity (Hall, 2007).

***Transformations of the instructional environments.*** Data indicated that transformations occurred in both instructional environments during the intervention. For example, pre-service teachers' discussion about using digital technology in social studies instruction increased in their course. Before the intervention, they indicated hesitancy to use technology in planning history instruction, viewing technology as an add-on or a possible hindrance to instruction. However, by the conclusion of the intervention, pre-service teachers' experience with blogging and witnessing middle-school students' enthusiasm about blogging in history seemed to sway their perceptions of digital technology use in history instruction. For example, many began to comment on the usefulness and importance of using technology to enhance instruction and how to make it more appealing and applicable to their future students.

In the middle-school classroom, multiple transformations were noted. Beyond those transformations already noted in the previous section, Ms. Wells began to consider more activities involving collaborative learning, discussion, and digital technology. We also saw evidence that she integrated more small-group discussion and disciplinary literacy in activities not directly related to the intervention. She explained that participating in the intervention helped her to understand and experience how disciplinary literacy could become a seamless part of history instruction, and she found multiple opportunities to incorporate disciplinary literacy into her lessons, whereas at the beginning of the intervention Ms. Wells instruction seemed more grounded in a transmission model of teaching history.

## **5. Conclusions**

Using a formative experiment allowed us to learn much about this particular intervention, specifically how it might be implemented effectively, efficiently, and appealingly to accomplish the specified pedagogical goals. For example, in gathering data and making modifications in response to that data, we learned that more explicit support than we had anticipated may be needed for students to write reflective blogs. More generally, we learned about the viability of disciplinary literacy as a concept through our attempts to integrate it into authentic instructional environments. For example, we discovered what resistance might be encountered from teachers, what difficulties students might have, and how these obstacles might be addressed. At the end of the study, we concluded that the intervention, given the modifications we made, is a reasonable and potentially useful one for promoting disciplinary literacy in social studies among middle-school students and among pre-service social studies teachers. The unanticipated outcomes of the intervention and its role in transforming the instructional environments were positive. However, undoubtedly other modifications are likely to emerge through further replication in similar and alternative contexts.

## **6. Some lessons learned**

Finally, we solidified and increased our understanding of formative experiments as a methodological approach to education research. In this section we highlight three lessons learned, or reinforced from our previous work, in this study.

### **The benefits and limitations of collaboration**

Collaboration between researchers and educators, which is a key element of conducting formative experiments (Reinking & Bradley, 2008) was clearly evident in this study and proved



to be an ongoing challenge, particularly because we had no established professional relationship with the teachers or schools in which we worked. On the other hand, collaborating for the first time with teachers in a new context can be an advantage, because we made no assumptions from prior experience about these teachers and students. Nonetheless, maintaining a strong professional relationship with the teachers and students, built on trust, is a constant challenge, especially when teachers' beliefs or instructional practices and decisions conflict with the underlying rationale for the intervention. Or, as was the case in the present study, a teacher may passively neglect to implement agreed upon elements of the intervention. We were able to circumvent these issues in part, we believe, because of the groundwork we laid in recruiting appropriate participants and carefully selecting contexts. We also view such obstacles as useful data and opportunities to be creative in adapting the intervention to conform to educators' needs, beliefs, and motivations.

This study reinforced our concerns about the extent to which researchers become part of the intervention or warp the authenticity of its implementation and consequently our findings. For example, we discovered during the study that the school principal, who had recently completed her dissertation research, had explicitly encouraged the teacher to cooperate in our study, thus potentially limiting the validity of some of our data and interpretations. Thus, an important consideration for design-based research, particularly formative experiments, is the negotiation of a researcher's role in an education environments under study and the effect that role may have on a study. How do we, as researchers, maintain a close relationship with teachers and instructors while distancing ourselves enough to ensure valid results and conclusions? Although it may seem contradictory, developing a close relationship with educators and drawing them into the research process may be one way to achieve this balance. Although Ms. Wells and Dr. Nelson did not participate directly in collecting or analyzing data, both were consulted on a bi-weekly basis to review iterative data analysis results and confirm or disconfirm data patterns observed in their respective classrooms.

### **Simultaneous, complimentary goals**

In our previous work, we have placed a single, carefully articulated pedagogical goal at the center of a formative experiment. In this instance we set two complementary goals for two related populations. That approach seemed logical, because disciplinary literacy and the intervention aimed at developing it applied to both populations of participants. Although that dual focus was enlightening, it was difficult to engage in rigorous data collection and analysis and to make modifications to the intervention that accommodated both groups. Consequently, we focused primarily on how the intervention affected the middle-school students and more incidentally on the pre-service teachers. Based on our experience, we suggest that other researchers carefully consider expectations, limitations, and available resources before they tackle investigating multiple goals, especially with more than one population.

### **More nuanced and pedagogically useful insights**

This study reinforced our belief that conducting formative experiments is a liberatingly expansive approach to research aimed at identifying promising instructional interventions. Unlike conventional experimental approaches, obstacles, even outright failures to achieve desirable results, are viewed as data and inspire creative thinking about how to design workable solutions to often difficult or problematic aspects of instruction. Gone is the subtle pressure to either achieve success or have nothing publishable to report. Further, conventional experimental approaches gloss over potentially critical nuances, which are often assumed to be random variation unrelated to the narrow range of variables under study. In contrast, every aspect of an instructional environment is potentially relevant and important in a formative experiment and

sustains efforts to confront less than satisfactory results toward improvement and accomplishing a goal.

Further, formative experiments are more likely to provide nuanced understanding of success, often revealing the most fundamentally important components of an intervention that lead to desirable outcomes, which may be overlooked when research is reduced to comparing statistical averages or simply describing passively what has been observed. Unlike conventional experimental approaches aimed at determining what works on average across diverse instructional environments, formative experiments are aimed at determining what it takes to make an intervention work in authentic contexts (see Ivey & Broaddus, 2007; Jiménez, 1997; Reinking & Watkins, 2000). Formative experiments also address more than just effectiveness in terms of measurable achievement, but the efficiency and appeal of an instructional intervention, as well as its unanticipated collateral effects. Consequently, we believe that the results of such research will be more directly relevant to practitioners and will help close the long-lamented divide between research and practice. Adding this study to our previous work, we remain increasingly enthusiastic about and committed to the advantages of this approach when compared to conventional experimental and naturalistic approaches. We hope that our brief summary of this study and our reflection about it will be helpful to others who share our enthusiasm and commitment.

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## A Professional Development Arrangement for Supporting Teachers' Enacting Inquiry-based Integrative Practical Activities in China

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# 24. A professional development arrangement for supporting teachers' enacting inquiry-based integrative practical activities in China

Qianwei Zhang, Joke Voogt, & Jan van den Akker

## Abstract

*This chapter describes the design and evaluation of a professional development arrangement in which curriculum materials are embedded. The purpose for the professional development arrangement is aimed at supporting teachers' enacting the integrative practical activities (IPA) to promote students' inquiry skills and IT skills in secondary schools in China. Four versions of the exemplary curriculum materials and two versions of the professional development arrangement are developed in total. The outcomes of preliminary investigation provide the basis for the design and development of exemplary curriculum materials and a professional development arrangement. The findings from formative evaluations and summative evaluation indicate that the exemplary curriculum materials as a tool for facilitating teachers' learning about innovative curricula are an essential component in the professional development arrangement. The video-clips demonstration as a component of the exemplary materials contributes to teachers' enacting IPA in particular. Findings reveal that a teacher professional development arrangement consisting of professional development workshop, exemplary curriculum materials, follow-up support, and organization support contributes to the enactment of student-centered IPA lessons.*

## 1. Introduction

In order to meet the challenges of the 21st century, the Ministry of Education (MOE) in China launched a new curriculum reform in 2001, which advocates quality education to promote the overall development of students. One of the main challenges in this curriculum reform was to transfer from the focus on knowledge acquiring and reciting towards developing students' abilities in problem solving and inquiring as well as cultivating innovative spirit and the sense of social responsibility (MOE, 2001a). To solve this problem a new course Integrative Practical Activities (IPA) was developed for students in Grade 3-12 (age 8-17), which was supposed to be more student-centered and inquiry-based (MOE, 2001b).

The main characteristics of IPA are as follows:

- a. *Integration.* The themes of IPA, which derive from the students' individual and social life, must embody the integration of the individual, society and nature, as well as the internal integration of science, art and morals.
- b. *Practicality.* The focus of the course is on activities, which stresses students get first-hand experience by doing, inquiring, serving, and experimenting.
- c. *Openness.* The objectives and content of IPA are open. It orients to the students' living world. And the content of the activities may vary with students in different classes, schools and districts.

- d. *Generation*. The IPA determined by its process-orientation and the development, emphasizes to develop the students' competencies (including attitudes, knowledge and skills) and the sense of values in the process of the activities.
- e. *Autonomy*. IPA respects the students' interests and preferences, which provides them ample room to fully develop their autonomy. Therefore, students can choose the learning themes, content, and the modes in line with their interests.

The IPA implementation has encountered several related problems. Because of a lack of comprehensive, systematic and effective in- and pre-service education teachers do not feel qualified to teach IPA. Also, appropriate curriculum resources and materials were not available, which aggravates the implementation problems.

This study is undertaken within the context of the new curriculum reform and its aim is to design and evaluate a professional development arrangement to support teachers' enacting IPA. Exemplary curriculum materials are considered as one of essential parts of the professional development arrangement.

## **2. Overview of the research and development activities**

With its emphasis on the usability of its findings for improving educational practice, design research was considered as an appropriate approach to meet the aim of the study.

The main research question was formulated as follows:

*What are the characteristics of a teacher professional development arrangement in which curriculum materials are embedded, that adequately support teachers in the enactment of IPA?*

To answer the question, the study has been guided by the following sub-questions:

1. What are the characteristics of the exemplary curriculum materials that support teachers in the enactment of IPA?
2. How should a professional development arrangement which aims to support teachers enacting IPA be structured?
3. What is the impact of the professional development arrangement on teachers' teaching IPA?
4. How does teachers' teaching IPA impact students' learning IPA?

Figure 1 presents an overview of the stages and development activities of the study. The white parts indicate the development process of curriculum materials. And the grey parts show the development process of the professional development arrangement. The three main stages are as follows: preliminary investigation, prototyping and formative evaluation, and summative evaluation.

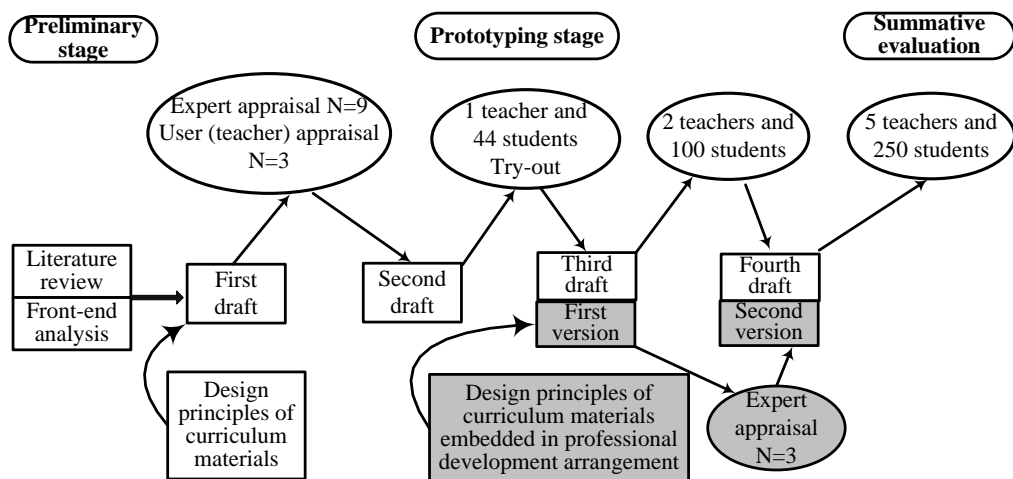


Figure 1: The design and evaluation process of curriculum materials embedded in professional development arrangement

### 3. Preliminary investigation

The study started with reviewing literature and making front-end analysis. The literature review on curriculum enactment, exemplary curriculum materials and teacher professional development provided the knowledge base for the design of the professional development arrangement in which curriculum materials were embedded. The front-end analysis gained insight into IPA policy and practices and revealed a gap between the intended and the implemented curriculum. IPA as a new course taught in secondary schools, teachers inevitably encountered various difficulties. The main difficulties reported by teachers were: lack of time and energy to prepare IPA, lack of curriculum resources, shortage of funds, and students' security during out of school activities. In addition, over half of the teachers had not received any form of training on IPA and did not know how to enact IPA in their teaching practice. Teachers desired for in-service education to acquire a student-centered approach to enact IPA in their practice. The literature review and the front-end analysis resulted in design guidelines for the development of the exemplary curriculum materials and the professional development arrangement.

#### Design guidelines for the IPA exemplary curriculum materials

As an important supporting tool for teachers attempting to change their practice, the exemplary materials play a crucial role in teachers' learning (Ball & Cohen, 1996; Beyer & Davis, 2009; Davis & Krajcik, 2005; Ottevanger, 2001; van den Akker, 1988).

In view of the information obtained from the front-end analysis and literature review, the following guidelines were formulated to guide the design of curriculum materials prototypes. The exemplary curriculum materials need to

#### 1. **Be consistent with national curriculum reform policies**

The documents from the Ministry of Education (MOE, 2001a, 2001b, 2001c) have sketched the background, rationale, content, and objectives of IPA. To support teachers enacting IPA, the design of exemplary curriculum materials should be aligned with the reform demands. And the rationale of IPA and clear learning objectives need to be provided.

#### 2. **Include procedural specifications**

Procedural specifications focus on essential but apparently vulnerable elements of IPA and provide the teacher with concrete 'how-to-do' suggestions for implementing IPA. The following elements were found vulnerable for the implementation of IPA: activity

preparation, activity procedures, teacher's role, group work, and assessment of learning effects.

#### *Activity preparation*

Concrete support in the planning and timing specific learning activities (e.g. van den Akker, 1988; Voogt, 1993), as well as the provision of (online) resources (background information and other references) required for the activities (including students' worksheets), and information about possible problems students may encounter during the IPA and how to cope with them (e.g. Thijs & Van den Akker, 2009).

#### *Activity procedures*

Actively in-depth learning through well-designed tasks focuses students around central questions and engages them in doing the work (Darling-Hammond, 2008). Focusing on student-centered approaches and the IPA goals, the exemplary curriculum materials are designed to involve students actively in the learning process through selecting and defining topics, conducting investigations and observations, collecting and analyzing data, making explanations about evidence, writing and presenting report. The activities are designed with emphasis on inquiry around topics and students' active engagement.

#### *Teacher's role*

Studies (Beyer & Davis, 2009; Davis & Krajcik, 2005; Mafumiko, 2006; Ottevanger, 2001; Schneider & Krajcik, 2002; Teclé, 2006; Van den Akker, 1988; Voogt, 1993) show that curriculum materials need to provide teachers with concrete suggestions to guide students in the learning process.

#### *Group work*

Collaboration and conversation are considered essential for IPA learning. Collaboration involves students in building a shared understanding ideas and the nature of the discipline as they engage in discourse with their classmates and adults outside the classroom (Krajcik, Blumenfeld, Marx, & Soloway, 1999). The exemplary materials need to pay careful attention in designing the collaboration activities so that both teachers and students can engage in them productively (Singer, Marx, & Krajcik, 2000). The materials are designed to provide support on teaching strategies of group work and suggestions for teachers to involve students, teachers, and members of society in a community of inquiry as they collaborate about the topics. And the work sheets provide students opportunities to work together in groups.

#### *Assessment of learning effects*

Curriculum, instruction, and assessment are integrated around meaningful performance in a real-world context. Performance tasks are central to the work of IPA and represent the ideas and modes of inquiry in IPA. Research suggests that inquiry-based learning demands thoughtfully structured performance assessments both to define the task and to properly evaluate what has been learned (Black & William, 1998a). Research on formative assessments suggests that feedback is more productive when it is focused on students' process and keyed on the quality of the work, offering comments for students to consider (Black & William, 1998b; Shepard, 2000). The designed exemplary materials need to provide teachers with evaluation criteria and tips on ways of assessments.

### **3. Use exemplary video clips**

Video clips demonstration could be seen as a special form of exemplary curriculum materials (Loucks-Horsley et al., 2010; Roes, 1997) and as valuable pedagogical tools in teacher education (Borko, Jacobs, Eiteljorg, & Pittman, 2008; Maher, 2008; Sherin, 2004). Video clips are also used as a way to bridge the perceived gap between the theory and practice (Bencze, Hewitt, Pedretti, Vaillancourt, & Yoon, 2003). The video recordings of exemplary lessons could serve as demonstrations of the 'ideal' performance but also

illustrate typical problems in practicing the lessons. The exemplary video clips would provide teachers concrete examples of what IPA lessons look like in and out the classroom when teachers enact IPA in their practice.

### **Design guidelines for the IPA professional development arrangement**

Based on the findings of the literature review and the front-end analysis, the following guidelines were formulated to guide the design of the professional development arrangement.

1. ***The professional development addresses teachers' needs and concerns.***  
Teachers' needs and concerns about IPA enactment are taken into consideration for the design of the professional development program (Hall & Loucks, 1978; Loucks-Horsley et al., 2010).  
The appropriate support needs to be provided to address teachers' concerns.
2. ***The professional development arrangement provides teachers with active learning opportunities.*** Active learning opportunities allow teachers to transform their teaching (Snow-Renner & Lauer, 2005). These opportunities often involve modeling the new strategies and constructing opportunities for teachers to practice and reflect on them (Garet, Porter, Desimone, Birman, & Yoon, 2001). By offering teachers active learning opportunities to apply new knowledge and skills to their teaching practice, their understanding of the new knowledge and skills will be developed and their students' learning will be facilitated.
3. ***The professional development arrangement has an appropriate time span necessary for change in practice.*** There is broad consensus that professional development activities need duration to provide teachers with ample opportunities to practice new knowledge and skills (Borko & Putman, 1996; Brown, 2004; Fullan, 2007; Guskey, 2000; Joyce & Showers, 2002; Loucks-Horsley, Stiles, Mundry, Love & Hewson, 2010; Penuel, Fishman, Yamaguchi & Gallagher, 2007; Penuel, Fishman, Gallagher, Korbak & Lopez-Prado, 2008).
4. ***The professional development arrangement consists of four components: exemplary curriculum materials, workshop, school follow-up support and organizational support.*** The four components interact with each other in such a way that they facilitate the effective professional development, teachers' and students' learning, and the implementation of innovation.

#### *Exemplary curriculum materials*

Exemplary curriculum materials are embedded in the professional development arrangement. Studies revealed that the exemplary curriculum materials systematically embedded in teacher professional development have the potential of supporting teachers' adopt innovation in teaching practice (Ottevanger, 2001; Teclé, 2006; van den Akker, 1988; van den Berg, 1996). In addition, the exemplary curriculum materials should effectively demonstrate what the IPA lessons look like and support the teachers' learning and practice about such lessons during workshops and later in the school.

#### *Workshop*

Workshops are structured opportunities for participants to focus intensely on topics of interests (Loucks-Horsley et al., 1998, 2010). They provide opportunities to understand the learning content, address real problems, explore and reflect, share participants' knowledge, and support. A workshop for the professional development of IPA implementation includes the following steps: theory study, video demonstration and lessons preparation.

#### *School follow-up support*

The professional development provides school follow-up support necessary for change in practice. Teachers need not only opportunities to practice what they learned from the workshop (Joyce & Showers, 1995, 2002), but also follow-up support for ongoing and job-

embedded professional development. The school follow-up support would contain the following characteristics:

- To support teachers' enacting IPA in their teaching practice, coaching is necessary for the school follow-up activities in the professional development arrangements, which involves providing teachers with technical feedback based on classroom observation or video watching, which involving assisting them to adopt new practice to their unique context and providing flexible coaching forms on the basis of individual teacher's concerns, helping teachers to examine and reflect the effects of their efforts, and encouraging them to continue in spite of minor frustration and fault.
- The concept of professional learning community (DuFour, 2004; Newmann et al., 1996) is taken as another main component of follow-up support in the professional development arrangement. Professional development experiences should strengthen the collaborative learning in an environment that is supportive, collegial, and integrative (Borko, 2004; Hammer, 2000; Wallace & Louden, 2002). Through professional learning community, teachers could share expertise and learn from each other. On the other hand, they can design and plan lessons collaboratively, watch each other and get feedback on their practice, and reflect on their teaching. They can also discuss the problems come across and find solutions.

#### *Organizational support*

The professional development arrangement should gain as much necessary support as possible from the district and school organization so as to accelerate the enactment of the innovation in the school. It is recognized (Fullan 2007; Loucks-Horsley, et.al., 1998, 2010; Joyce & Showers, 1995, 2002) that leadership is one of the most important factors in promoting teacher and student learning, therefore, the professional development arrangement should engage principals and district leaders in supporting teachers' professional development.

## **4. Prototyping and formative evaluation of the exemplary curriculum materials**

### **Prototyping**

The prototyping stage primarily focused on the iterative design and formative evaluation of successive prototypes of the exemplary materials and the professional development arrangement.

To determine the quality of the prototype Nieveen's (1999) distinctions between validity, practicality and effectiveness of a curriculum product/process (in this study the exemplary curriculum materials and the professional development arrangement) was used:

- *Validity* refers to the state-of-the art knowledge (content validity) and the internally consistent arrangement of products or processes (construct validity).
- *Practicality* implies that users and other experts consider the prototype as appealing and usable under normal circumstances.
- *Effectiveness* means that the experiences and outcomes from the users of the prototype are consistent with the intended aims and that user's task performance is improved.

### **Formative evaluation of the exemplary curriculum materials**

Based on the design guidelines the exemplary materials were developed (see also <http://doc.utwente.nl/80454/>). The main parts of the first version include **activity preparation** (activity overview, estimation of time, suggestions for task organization), **activity content**

(activity objectives that specify desired outcomes, outline of students' activities), **teaching role** (scenarios for activity start, grouping students for an activity), and **activity assessment** (performance tasks, formative assessment, and guidelines for portfolio assessment). The formative evaluation of the first version of the exemplary materials resulted in feedback from experts and users indicated the validity of the exemplary materials. And following concrete suggestions for improving the prototype were provided. The main revisions focused on the objectives, time allocation, and tasks of activity as well as gaining multiparty support for enactment.

The second version of the materials was used with one teacher and 44 students in the try-out. The overall opinion of the teacher and students was positive. The revision decisions generating from this try-out were used to improve the practicality of the exemplary materials. As practical examples of IPA lessons, the video clips resulting from the try-out teacher were prepared. In addition, suggestions for teachers to support their students in revising their research proposal, data collection instruments, and research report were also provided. More reference materials and resources were needed to offer for teachers and students.

The third and fourth versions of the prototypes of the exemplary materials were developed to evaluate the impact of the exemplary materials embedded in the professional development arrangement.

## **5. Formative and summative evaluation of the professional development arrangement**

### **Methods**

In this study, the five levels (Guskey, 2000) were used to evaluate the professional development arrangement to form an evaluation framework. Level 1 was data on teachers' satisfaction with the professional development arrangement, level 2 and 3 were respectively on teachers' learning from the arrangement and organizational support for teachers, level 4 served primarily to help to interpret information on teachers' actual enactment in- and outside the classroom practices, which was seen as the main indicator for the practicality of the professional development arrangement, while level 5 on students' experiences with IPA and their learning results from these activities were considered to be the main indicator for the effectiveness of the professional development experience with IPA.

During the formative and summative evaluation, triangulation of multiple methods was employed to overcome the weakness of each of data source and minimize uncertainty in data interpretation. The entire data collection process was organized in three stages that were conducted at different points in time. Before implementing the professional development arrangement, baseline data were gathered. And in the implementation of the professional development workshop and the school follow-up support, data about teachers' reactions, learning, and use of new knowledge and skills were collected. The last stage was carried out at the end of school follow-up support. Table 1 provides an overview of the data collection instruments used in the formative and summative evaluation.

Table 1: Data collection instruments used in formative and summative evaluation

Evaluation level	Stages of data collection		
	Prior to intervention	During intervention	After intervention
Participants' reactions	▪ ExQ	▪ EQ	▪ TI*    ▪ SFSQ
Participants' learning		▪ EQ	▪ SFSQ    ▪ TI* ▪ TRB*    ▪ RLB*
Nature of school support			▪ SSQ    ▪ PIOS ▪ TISS*
Participants' use of new knowledge and skills		▪ CP*	▪ SI    ▪ TIE    ▪ TRB* ▪ LoUI    ▪ RLB*
Students' learning outcomes			▪ SQ*    ▪ TI*    ▪ PI ▪ SI*    ▪ SP*

Note \*: Instruments used in the formative evaluation. ExQ: Expectation Questionnaire (Teachers); EQ: Evaluation Questionnaire (Teachers); CP: Curriculum Profile; SFSQ: School Follow-up Support Questionnaire; SSQ: School Support Questionnaire; TI: Teacher Interview; TIE: Teacher Interview for Enactment; TISS: Teacher Interview for School Support; TRB: Teacher Reflection Blog; PISS: Principal Interview for Organizational Support; LoUI: Level of Use Interview; SI: Student Interview; SQ: Student Questionnaire; SP: Student Product; PI: Parent Interview.

### Formative evaluation of the professional development arrangement

#### *The first version of the professional development arrangement*

Based on the design guidelines for the professional development arrangement and the feedback from the try-out of the exemplary curriculum materials, the first version of the professional development arrangement was developed (see <http://doc.utwente.nl/80454/>). It was designed into two parts: a professional development workshop and follow-up support activities closely related to teachers' classroom practice. The workshop was structured into the following three main sessions: study of theory, demonstration of intended practice, hands-on practice and feedback. And the follow-up support activities include school support environment, school-based workshops, and technical coaching.

#### *Respondents*

In the study two teachers and 100 students were involved. With the help of the director in charge of the IPA teaching and research in Yuexiu District, the researcher found the two teachers from two ordinary schools would like to take part in IPA enactment. The school leaders would like to provide necessary support for the enactment. And traffic convenience was also taken into consideration.

#### *Findings*

Both teacher and students had positive experiences with IPA and were fond of IPA, able to enact the activity in their classes, and found it helpful in adopting student-centered approach.

##### *Level 1: Teachers' satisfaction*

The two teachers were positive about the professional development arrangement. They spoke highly of the video demonstration and found the exemplary video-clips helpful for identifying the main features of IPA lessons. In addition, teachers indicated the exemplary curriculum material was helpful in carrying out IPA lessons and it provided support for teaching in a more student-centered manner. The teachers stated that the researcher's exchanging views before class and



providing timely feedback after class facilitated them making full preparation for the activity and reflecting the teaching practice. Teachers' reflections also indicated that their exposure to IPA enhanced their understanding the IPA theory as well as practical skills to guide IPA.

*Level 2: Teachers' learning*

Regarding teachers' learning from the professional development arrangement, teacher A tended to understand the rationale of IPA quickly and adopted inquiry learning in her teaching practice. The students in her class were actively involved in the activities and benefited a lot from the activities. At first, Teacher B used most of the time on lecturing. Later the researcher exchanged ideas with him, and teacher B allocated more time for student activities and paid attention to guide students.

*Level 3: Organizational support*

The principals of the two schools encouraged the teachers to enact IPA and provided some resources and facilities. However, the level of support was different in each school.

*Level 4: Teachers' enacting IPA*

The two teachers have applied the knowledge and skills they had acquired in the professional development arrangement in teaching IPA. They adapted the exemplary curriculum materials to their context, Nevertheless, teacher A performed better than teacher B. While enacting IPA, the teachers would encountered some difficulties such as large number of students, time allocation, and the safety issues when students go out of school for investigation and interview.

*Level 5: Students' outcomes*

The results showed that the majority of the students experienced IPA positively. The results from questionnaire in Table 2 clearly demonstrated that the majority of students had very positive attitudes to and experiences with IPA. Most students seemed to like IPA because the activity is novel and interesting and broadens their vision. It made students enjoy the IPA classes and they reported that they learned a lot about the topics they explored. Apart from being novel and interesting, students appreciated the opportunity to do an investigation outside school most as compared to former Activities, which were normally carried out without a field investigation session.

*Table 2: Students' attitudes to and experience with IPA*

Item	School A (N=51)			School B (N=49)		
	M*	SD	Agree or strongly agree in %	M*	SD	Agree or strongly agree in %
I am interested in the learning of the topic	4.5	0.50	100.0	4.3	0.62	95.9
I like the course of IPA	4.5	0.54	98.0	4.7	0.56	95.9
I am satisfied with the effect of the topic learning	4.4	0.60	94.1	4.4	0.68	93.9
I feel comfortable with group activity in IPA	4.6	0.66	90.2	4.5	0.71	91.8
I gained in many aspects from IPA	4.7	0.46	100.0	4.7	0.46	100.0
I experienced the hardships and pleasure of the activity	4.8	0.49	96.1	4.7	0.62	95.9
The student worksheets are helpful for me to fulfill tasks	4.7	0.55	96.1	4.6	0.61	93.9

Note. \*Legend: 5= strongly agree ; 4= agree ; 3= not sure ; 2= disagree ; 1= strongly disagree

The results in Table 3 show that the majority of the students agreed that they actively participated in IPA and they fulfilled the tasks they undertook in earnest. Most of the students thought that they could finish tasks in time with high quality.

Table 3: Students' performance in IPA

Item	School A (N=51)			School B (N=49)		
	M*	SD	Agree or strongly agree in %	M*	SD	Agree or strongly agree in %
I actively participate in every activity	4.6	0.57	96.1	4.5	0.82	93.9
I fulfill the tasks I undertake in earnest	4.7	0.55	96.1	4.6	0.54	98.0
I can finish my tasks in time with high quality	4.3	0.72	88.2	4.2	0.58	91.8

\*Legend: 5= strongly agree; 4= agree; 3= not sure; 2= disagree; 1= strongly disagree

Apart from helping them develop their courage and increase their self-confidence, students indicated that many abilities such as communicating with others as well as applying knowledge comprehensively to solve practical problems were enhanced after participating in the activity. Table 4 shows that the students from the two schools, who completed the questionnaire, thought they gained greatly in many aspects from IPA. It also indicates that the majority of the students who had fulfilled their tasks earnestly benefited a lot from the activities. The analysis also showed the students' positive attitude change towards the IPA teaching.

Table 4: Ability perception after taking part in IPA

Item	School A (N=51)			School B (N=49)		
	M	SD	Agree or strongly agree in %	M	SD	Agree or strongly agree in %
Pay close attention to the issues in society and life	4.7	0.49	98.0	4.5	0.54	98.0
Handle affairs in a planned way	4.5	0.61	98.0	4.4	0.58	96.0
Pay attention to reflect on the process and outcomes of the learning	4.5	0.64	92.2	4.2	0.60	91.9
Ability for cooperating with others is improved	4.5	0.81	94.1	4.6	0.86	93.9
Ability for communicating with others is improved	4.6	0.78	96.1	4.6	0.60	93.9
Ability for collecting, analyzing and arranging information is improved	4.5	0.58	96.1	4.4	0.76	87.8
Ability in oral and written expression is improved	4.6	0.53	98.0	4.2	0.76	87.8
Ability of exploiting ICT in learning is improved	4.6	0.59	98.0	4.4	0.88	87.8
Ability for applying knowledge comprehensively to solve practical problems is improved	4.7	0.44	100.0	4.4	0.61	93.9
Struggle with difficulties and frustration	4.7	0.59	98.0	4.0	1.25	71.4

Note. \*Legend: 5= strongly agree; 4= agree; 3= not sure; 2= disagree; 1= strongly disagree

### *Revisions*

Based on the results of the formative evaluation, the study suggested incorporating not only more examples in the workshop to help teachers understand the enactment of IPA in teaching practice, but also examples of the students' products and specific materials on research methods for students and teachers in the exemplary curriculum materials. Video clips were carefully chosen and edited. In addition, discussion questions for reflection were designed to be used in the video demonstration session. A school-based professional learning community was suggested as a way to organize school follow-up support, and this suggestion was implemented in the second field study.

### **Summative evaluation**

#### ***Respondents***

The second version's impact of the professional development arrangement (with embedded exemplary curriculum materials) on teachers' teaching IPA and students' learning IPA was empirically assessed in the second field study. Five teachers and 250 students from three schools (A, B and C) participated in the evaluation. The summative evaluation study enabled the researcher to make an overall judgment about the effectiveness of the professional development arrangement. The results of summative evaluation are discussed in the following sub-sections.

#### ***Findings***

##### *Level 1: Teachers' satisfaction*

The results revealed that teachers were positive about the professional development arrangement. They thought the professional development arrangement was useful for their enacting IPA and further understanding IPA. Teachers were satisfied with the contents of professional development workshop and the follow-up support activities. They appreciated the provision of exemplary curriculum materials, particularly the demonstration of video clips, excellent examples of students' products, and resources related to the topics that students inquired. However, teachers disliked their fellow teachers commented on his/her video-taped classroom lessons face to face.

##### *Level 2: Teachers' learning*

Teachers found that the professional development arrangement enlightened their awareness and facilitated understanding about IPA lessons. The video-clips demonstration assisted the teachers in identifying the important features of IPA lessons and made them consider attempting IPA lessons. Sharing teaching plan including slides was conducive to sharing expertise.

##### *Level 3: Organizational support*

With regard to organizational support, there were differences across the three schools. Both school B and C encouraged teachers to experiment with new strategies. School B provided necessary resources for IPA enactment. School A was considered less supportive in school leadership and collegial support. All teachers indicated the time for lesson preparation was not sufficient. School B and school C could provide participating teachers fixed time and rooms to organize teacher learning communities for sharing expertise. The district teaching and research center honored the students' excellent works in the district and required teachers to submit articles about the IPA enactment to exchange ideas with the teachers in other schools.

##### *Level 4: Teacher enactment of IPA*

Concerning teacher use of new knowledge and skills, level of use (LoU; Hall & Hord, 2006), classroom practice profile scores, teachers' perception, and students' perception on teachers'

enacting IPA has been probed. Results showed that there are differences in the quality and extent of teachers' adoption of a student-centered approach. An overview of the results on teacher enactment is presented in Table 5.

Table 5: Summary of the five teachers' enactment

	A	B1	B2	C1	C2
Level of Use	Routine	Refinement	Integration	Integration	Mechanical
Practice profile	Moderate	Good	Good	Excellent	Low
scores basic skills	(29)	(31)	(33)	(36)	(20)
Practice profile	Moderate	Low	Moderate	Good	Low
scores ideal skills	(38)	(20)	(39)	(50)	(28)
Student perceptions	Positive	Positive	Positive	Positive	Positive

#### Level 5: Students' outcomes

Impact of the professional development arrangement on students was positive. The analysis of students' questionnaire and interview as well as parents' interview showed students' positive attitudes towards IPA teaching. The majority of the students could actively take part in IPA and improved their knowledge and skills in aspects such as posing questions, communicating with others, cooperating with classmates, designing questionnaire, making survey, and analyzing data. Table 6 shows the students' reactions to IPA questionnaire.

Table 6: Students' perceptions of the activity

	<i>M*(SD)</i>					ANOVA (F)
	Class A	ClassB1	ClassB2	ClassC1	ClassC2	
	N=17	N=42	N=53	N=46	N=39	
Attitudes to and experience with IPA	4.0 (0.75)	4.4 (0.48)	4.5 (0.33)	4.5 (0.46)	4.4 (0.46)	4.099**
Performance in IPA	4.0 (0.72)	4.4 (0.41)	4.5 (0.42)	4.5 (0.46)	4.2 (0.41)	4.645**
Ability perception	4.0 (0.62)	4.4 (0.46)	4.5 (0.35)	4.5 (0.44)	4.4 (0.38)	4.300**

Note. \*Legend: 5= strongly agree; 4= agree; 3= not sure; 2= disagree; 1= strongly disagree; \*\*P<0.001

## 6. Overall outcomes of the study: An answer to the research questions

### Characteristics of exemplary curriculum materials

To a great extent, the study results suggest that the curriculum materials are valid, practical, and effective in secondary schools. Based on the findings of this study, the student worksheets and the exemplary video clips were highly appreciated by the teachers and appeared to work best. Teachers thought the students' worksheets very practical and the exemplary video clips helpful for identifying the main features of IPA. However, the teachers mentioned that it was not easy for a single teacher to organize IPA because of the large class size.

*Box 1: A summary of the main characteristics of exemplary curriculum materials*

<p><b>General description of the activity:</b> provide the general overview of the activity and describe what the activity looks like, sequence of each session of IPA, general and specific information on preparation and execution of IPA; indicate learning outcomes expected to be achieved by the students at the end of each activity.</p>
<p><b>Activity preparation:</b> activity plan and timing: suggestions on specific learning activities and timing each activity; provide online resources (background information and other references) required for the activity; offer information about possible problems students may encounter during the activity and how to cope with them.</p>
<p><b>Activity procedures:</b> provide a list of instructional objectives that clearly specifies the desired outcomes of the activity; offer suggestions on how to determine the topics according to student age level, how to select available information for students, how to introduce research methods, and how to draw conclusions from each activity.</p>
<p><b>Teacher's role:</b> provide concrete suggestions for the teacher's role during activity execution; for instance, suggestions for grouping: to guide teachers in using groups for group investigation, small group discussions, and group presentation to promote student active participation in the process of learning; provide suggestions on how to support investigations and how to prepare online resources for supporting student inquiry.</p>
<p><b>Monitoring and assessing students' learning:</b> describe the students' potential learning effects; provide suggestions for the assessment indicators of student products, group performance and individual performance, and on how to use portfolio assessment.</p>
<p><b>Students' worksheets:</b> provide an overview of the purpose of each session of IPA; offer information on procedures guiding questions for research proposal, investigation schema, and research report; follow-up assignments. The worksheets are also included in the teacher materials.</p>
<p><b>Exemplary video clips:</b> describe the main features of IPA and what IPA looks like in practice.</p>

**The structure of teacher professional development arrangement supporting IPA enactment**

The results showed that the professional development arrangement enlightened teachers' awareness and understanding about IPA lessons, and their knowledge and insights about IPA were developed. Regarding the four components of the professional development arrangement (workshop, exemplary curriculum materials, school follow-up support, school support environment), the workshops were relatively easy to implement. Teachers encountered several problems such as lack of enough time to enact IPA and lack of administrative support. Despite these trade-offs the professional development arrangement is valid and effective; its practicality would be improved by providing teacher explicit time and support for IPA enactment. The components of the professional development arrangement are outlined in Box 2.

*Box 2: A summary of the professional development arrangement*

**Components of the professional development arrangement**

***Professional development workshop***

- *Theory study*: researcher introduced the workshop objectives, discussed about participants' responses to the questions, and presented the rationale of IPA teaching and how to enact IPA; and provide reading materials on new curriculum reform, IPA, and inquiry learning as well as exemplary materials.
- *Video demonstration*: researcher demonstrated video clips on how the new practices should be enacted in and out of classroom for teachers, and teachers reflected on their practice.
- *Lessons preparation*: researcher introduced the exemplary curriculum materials and teachers walked through the exemplary materials and developed a plan for teaching one lesson from those materials, then brainstormed to discuss and decided the topics available for the students; finally, researcher provided feedback and teachers reflected on their preparation.

***Exemplary curriculum materials***

The exemplary curriculum materials supported teachers' learning and practice regarding IPA lessons during the workshop and later in the schools. The main elements of the exemplary curriculum materials are described in the previous section.

- *Activity preparation*;
- *Activity procedures*;
- *Teacher's role*;
- *Group work*;
- *Assessment of learning effects*;
- *Exemplary video clips*.

***School follow-up support***

- *School-based workshops*: researcher established a schedule of times and places to meet once or twice a week, introduced teachers with the follow-up scenario of the study, completed the stages of concerns questionnaire in the first workshop, handed out exemplary examples of IPA lessons and students' products in each stage; teachers observed short video-taped lessons of a fellow teacher, then made comments on it; prepared for lessons together; shared teaching plan (including slides) with other teachers; reflected upon their teaching by writing logbook (Blog); wrote articles about their own work; discussed common problems collectively and learnt on topics such as how to reflect on their teaching practice, how to guide student group work, design questionnaire, make survey, and write report etc.
- *Technical coaching*: The researcher provided feedback to teachers based on classroom observation or video watching, provided concrete suggestions and tips for next lessons, discussed the problems encountered and finding solutions together with the teachers, provided excellent examples of students' products, and provided online resources, audio, video and written materials related to the topics inquired.

***School support environment***

Establishing a supportive school environment involved garnering as much as possible from the school leadership. The researcher:

- informed school leaders about the scheme of IPA enactment
- coordinated the professional development arrangement with school development planning
- handed out the exemplary curriculums materials
- exchanged views with school leaders regularly based on classroom observations
- developed ongoing meaningful dialogue between staff members in a respectful, mutually supportive environment.

### **The arrangement impact on teachers' learning and teaching IPA**

Teachers thought the professional development arrangement enlightened their awareness and helped them further understanding IPA lessons. Regarding the four components of the professional development arrangement, the workshops were relatively easy to implement. All the teachers indicated that the workshop enhanced their understanding IPA, satisfied their expectation and was relevant to their teaching practice. All the teachers reported that the video-clips demonstration helped them to identify the important features of IPA lessons and made them look forward to attempting IPA lessons. Teachers indicated that sharing teaching plans with other teachers was conducive to sharing expertise.

Teachers were fond of that they could use the exemplary materials and subsequently contributed to the modification of the exemplary materials. They had opportunity to study the exemplary materials, reflect on their teaching, discuss their opinions with researcher and colleagues, and suggest alteration to the materials that would make the teaching more effective.

The establishment of a supportive school environment is also very important for the IPA enactment in daily practice. However school follow-up support activities were difficult to implement. Above all, there were many contextual factors affecting the school follow-up support activities, such as personnel, facility, and time. Teachers reported that they had not enough time to reflect on their teaching because of the heavy workload. The cultural background needs to be taken into consideration when carrying out school follow-up support activities. For example, some teachers did not like the activity to observe the video-taped classroom lessons and were reluctant to be commented by the fellow teachers. It is as one teacher explained: "Some Chinese were not used to be commented in public by the fellow teachers. It would be better to exchange views in private." All teachers indicated that the time for lesson preparation was not sufficient. Teachers' perceptions about the implementation conditions affected their enacting IPA to some extent. The district teaching and research center honored the students' excellent works and required teachers to submit articles about the IPA enactment to exchange ideas with teachers in other schools in the district.

Teachers adopted a student-centered approach with various quality and degree and all the five teachers were users (from mechanical to integration) of IPA. Teachers acquired skills on guiding students to conduct IPA, making choice on topics and time management, evaluating students' performance during the activities, arousing the students' enthusiasms and engaging them in integrating IPA teaching with other subjects.

### **IPA teaching impact on students' learning**

Students had positive attitudes towards IPA teaching. The majority of students actively took part in the activity and improved their knowledge and skills in the following aspects such as posing questions, communicating with others, cooperating with classmates, designing questionnaire, making survey, and analyzing data. Parents also indicated that the students' knowledge and skills were developed through IPA in many aspects, such as integrated knowledge, social practice, cooperation, independent thinking.

## **7. Yield of the project**

### **Contribution to the knowledge base**

One contribution of this study to the knowledge base is the design guidelines for exemplary curriculum materials and professional development arrangement. The design guidelines of

exemplary curriculum materials are to be consistent with national curriculum reform policies, include procedural specification (activity preparation, activity procedures, teacher's role, group work and assessment of learning effects), and use exemplary video clips. This study has confirmed findings from previous research about the effectiveness of the exemplary curriculum materials as a tool for facilitating teacher learning about innovative curricula (cf. Mafumiko, 2006; Motswiri, 2004; Van den Akker, 1988; Voogt, 1993). The exemplary curriculum materials offered teachers concrete lessons to use and provided them practical experience. The exemplary curriculum materials also allowed teachers to redesign the materials or create their own lesson materials according to their context.

The design guidelines for the professional development arrangement intended to provide teachers active learning opportunities and a long time span for practice. From the perspective of curriculum enactment, the design guidelines indicate that professional development arrangement is effective when it consists of a combination of exemplary curriculum materials, workshop, school follow-up support and organizational support. The role of curriculum materials as a component with teacher professional development arrangement has reconfirmed previous positive findings (cf. Ottevanger, 2001; Roes, 1997; Teclé, 2006; van den Berg, 1996). The study has shown that a professional development arrangement with four main components has the potential to support teachers' learning and enacting IPA teaching in practice. When the professional development workshop, exemplary curriculum materials, follow-up support, and organizational support are systematically integrated and extended over time, they are more likely to impact on teachers' learning and practice. The professional development arrangement can lead to the improvement in participating teachers' learning and classroom practice.

In this study the enactment perspective on curriculum implementation is applied for teachers' enacting IPA. The enactment perspective emphasizes that teachers and learners jointly create the IPA curriculum, as is considered essential in the rationale of IPA. This approach fits in current thinking about the role of teachers in making the curriculum (e.g. Clandinin & Connelly, 1992; Craig & Ross, 2008). The exemplary curriculum materials served as a procedural guide and provided examples on what IPA can look like in practice. However, because teachers and students jointly have to decide about the IPA topics, the teachers could not simply use or adapt the exemplary curriculum materials. Teachers and students therefore developed and enacted their own curriculum in their specific context with the exemplary curriculum materials. Not only teachers involved in IPA enactment did contribute to the further development of the exemplary curriculum materials, but also redesigned their own practice. The researcher, working collaboratively with a group of teachers who engaged in their classroom practice, could listen to the teachers' voice and facilitate the process of curriculum enactment.

### **Contribution to practice**

The major contribution of this study to practice is the design and implementation of the professional development arrangement which is viable and effective for supporting teachers' enacting IPA in the context of the new curriculum reform. One element of curriculum materials was to integrate video-clips demonstration into professional development as a pedagogical tool in teacher education. The video demonstration showed the teachers what the IPA lessons look like in practice and was helpful for identifying the main features of IPA. This seems a productive strategy for facilitating teachers' learning and the materials themselves. The student worksheets were also very practical for teachers' enacting IPA. The contextual factors, such as time and cultural background need to be taken into consideration while implementing school follow-up support activities. Instead of microteaching, teachers and the researcher gathered together to



discuss the topics prepared for students before the enactment and prepare the lesson plans before each lesson was more useful for IPA training. Teachers could experience the process of how to choose appropriate topics and the possible problems encountered as students. The endeavors of researcher and teachers positively impact the students' learning and help them find their experiences that are personally and socially meaningful. In brief, it can be concluded that the professional development arrangement consisting of professional development workshop, exemplary curriculum materials, follow-up support, and organizational support contributed to the teachers' enacting a more student-centered IPA lessons in secondary schools in China.

## **8. Reflections on the research methodology**

### **Design research and the research-practice gap**

The design and the development of the intervention dynamically evolved, based on the state-of-the-art knowledge used in the professional development arrangement, as well as on the comments, suggestions, and needs from experts and teachers. Theoretical analyses in teachers' learning and professional development from the perspective of curriculum enactment as well as the potential of exemplary curriculum materials embedded in the professional development arrangement provided insight into the design of the intervention.

The teacher professional development arrangement has bridged research and practice in both university and school contexts, and set an example of how research and practice can come closer together to improve IPA teaching and learning in secondary classrooms.

### **Design research in the context of China**

In recent years, design research has aroused Chinese researchers' interest in order to improve educational policies and practices and change the paradigm of educational research. Although some authors (Chen & Jia, 2008; Liu, 2010; Liu, Yang & Kan, 2009) claim they adopt design research in their studies, problems can be found by reviewing these studies: research questions are not clear, there is a lack of a relevant knowledge base, an insufficient literature review, an inappropriate intervention scheme, no iterations at all or too few iterations, and triangulation of research methods are not employed etc.

This study adopted design research has provided an example of how to conduct design research in the context of China. The exploration can enhance the influence of design research in the field of educational research in China.

### **The role of the researcher**

One of the benefits of the design research approach is that it stimulates the researcher to learn and perform a number of (new) roles. In the development and evaluation of the intervention, the researcher performed such roles as designer, implementer, and evaluator; as observer and facilitator in the classroom observation; as trainer and facilitator in the workshop and follow-up support. The researcher was afforded the opportunity to gain deeper insights into the strengths and weakness of the intervention. And the researcher obtained a great deal of knowledge and many new skills from those roles and understood the implementation further. In order to prevent response bias and interpretation bias, much attention has been paid to triangulation of research methods, data sources, evaluators and theory (McKenney, Nieveen; & Van den Akker, 2006). These measures have contributed to the reliability and validity of the findings.

## Key source

Zhang, Q.W. (2012). *Supporting teachers to enact integrative practical activities in China*. Doctoral dissertation. Enschede, the Netherlands: University of Twente.  
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## The Model of Educational Reconstruction: A framework for the Design of Theory-based Content Specific Interventions. The example of Climate Change

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# 25. The model of educational reconstruction: A framework for the design of theory-based content specific interventions. The example of climate change

Kai Niebert & Harald Gropengiesser

## Abstract

*The teaching and learning of science is the main focus of science education. It requires fruitful strategies to engender a conceptual understanding. The model of educational reconstruction (MER) is a widely used research programme that was developed to improve content specific learning and teaching. The MER integrates the perspectives of students and scientists in order to design learning environments. By example of an educational reconstruction of climate change we show how the MER can help to analyse, design and evaluate learning environments fostering a conceptual understanding. We collected students' conceptions by (a) reanalysing 24 studies on everyday conceptions of global warming and by (b) conducting an interview study with 35 18-year old students from German grammar schools. Climate-scientists conceptions were analysed from textbooks and research reports in a literature study. All data were analysed by systematic metaphor analysis and qualitative content analysis. A theory of embodied cognition and metaphor provided insight in the process of understanding. Hereby we developed a theory of students' understanding of climate change by identifying different thinking patterns in students' and scientists' conceptions. Following the MER we took these conceptions as a starting point for the design of learning environments and evaluated these in teaching experiments.*

## 1. Introduction

Science education is concerned with the learning and teaching of science content and practices. It therefore requires "pedagogical content knowledge, that amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, 8). Pedagogical content knowledge (PCK) is not readily available. It has to be elaborated and studied, based on evidence, method, and theory; therefore it requires expertise in the subject studies and in the educational sciences as well. It is not surprising that researchers in science education are more prone to one than the other science. Some researchers in science education set their priorities in bringing current knowledge of the discipline into the classroom or working on the optimal presentation of experiments in the classroom. However others lay more weight on educational matters and explore for example the effect of media or the relationship between methods and interests in communicating their subject. This typological distinction of science education research can as well be seen as the difference between humanities and science or between applied sciences and fundamental research.

The research program of Educational Reconstruction sets both traditions into relation trying to bring them into balance. The model of educational reconstruction (MER) stands on two feet – one foot in the discipline and the other in education. Both perspectives are brought together to design domain- and topic-specific theories of teaching and learning science.

The MER is a framework for research on content specific learning and teaching. Researchers working with the model analyse, design and evaluate instructional approaches striving to facilitate learning and teaching. This results in content-oriented theories on conceptual development (design-based research) as well as in evidence-based and theory-guided analysis, design and evaluation of learning environments (research-based design). Thereby the knowledge is reconstructed for instruction with respect to the scientists' perspectives and the capabilities of the students as well. The process that transforms (or translates) domain specific knowledge into knowledge for instruction we prefer to call *reconstruction*. The content structure of the discipline differs from the content structure for instruction in that the latter is reduced to the elementary ideas but also enriched by contextual embedding and customizing and thereby reconstructed. The curriculum developers' awareness of the students' point of view will substantially influence the reconstruction of the particular science content. This is a key assumption of the MER (Duit, Gropengiesser, Kattman, Komorek, & Parchmann, 2012).

With the following study we show how the MER serves as a framework to develop a theory of students understanding of climate change and subsequently leads to a theory-guided and evidence-based design of learning environments. In our study we interviewed 35 18-year-old students in German schools regarding their beliefs about the causes and processes of climate change. The student Emily gave a typical answer:

*“CO<sub>2</sub> is a man-made gas that bites a hole in the ozone layer. Through this hole, more sun rays enter the atmosphere and it warms up.”* (Emily, 18 yrs.)

Emily believes that climate change is caused by CO<sub>2</sub>, which she imagines to be a man-made gas that causes holes in the atmosphere. These holes allow increased radiation from the sun's rays. Scientists relate global warming to an increased greenhouse effect caused by greenhouse gases like CO<sub>2</sub> that absorb infrared-radiation. The majority of these greenhouse gases are from natural and not from man-made sources, causing a natural greenhouse effect. This effect is increased by man-made emissions of additional greenhouse gases. Emily and the scientist are in partial accordance as pertains CO<sub>2</sub> as a cause and the effect of warming but in sharp contrast as to explain the causal connexion. Emily is not alone in her scientifically incorrect way of explanation. We analysed 24 studies published in refereed journals dealing with conceptions of climate change (Niebert & Gropengiesser, 2012, 2013). These studies collected data from primary school, high-school, and university students, educated laypersons, and adults with and without science degrees. The data were collected in different parts of the world, including Europe, the United States, Canada, Asia, and Australia. Nevertheless, the results were similar everywhere. Most students and educated laypersons:

- Confuse different environmental problems related to the atmosphere, such as the greenhouse effect, the ozone hole and air pollution. The most prominent explanation for global warming is that the ozone hole causes climate change (Bostrom, Morgan, Fischhoff, & Read, 1994; Boyes & Stanisstreet, 1997; Read, Bostrom, Morgan, Fischhoff, & Smuts, 1994).
- Mix up the causes for the emissions of greenhouse gases and their effects on the atmosphere. Often, they describe the burning of fossil fuel as the only source of greenhouse gases (Koulaidis & Christidou, 1999; Sterman & Booth-Sweeney, 2007).

- Often relate to scientifically inadequate conceptions - even after instruction (Ekborg & Areskoug, 2006; Pruneau, Moncton, Liboiron, & Vrain, 2001).

Our study is an evidence-based and theory-guided design of learning environments on the greenhouse effect. For our study, we adopted Lakoff and Johnson's (1999) theory of experientialism, that draws on the embodied mind and metaphor. We analysed the experiential sources of students' and scientists' conceptions. Viewing Emily's conceptions through the lens of experientialism, she uses metaphorical terms, such as "CO<sub>2</sub> bites a hole", "a man-made gas", and "enter the atmosphere".

## 2. Shedding light on conceptions

In prior research (Gropengießer, 1997; Riemeier & Gropengießer, 2008) it has proved to be fruitful to analyse the experiential sources of students' pre-instructional knowledge and scientists' conceptions for the design of learning activities. To shed light on the source of students' and scientists' conceptions, we refer to theoretical considerations and empirical findings emerging from the fields of cognitive linguistics (Lakoff, 1987; Lakoff & Johnson, 1980), philosophy (Johnson, 1987), science education (Gropengießer, 2007; Niebert, Marsch, & Treagust, 2012), and neurobiology (Gallese & Lakoff, 2005; Rohrer, 2001, 2005), summarised as experientialism.

Experientialism holds that abstract concepts -this refers to most concepts in science -are understood imaginatively, thereby drawing on directly meaningful concepts and schemata. These basic conceptions are embodied, that is, they are grounded in bodily experience with our physical and social environment, e.g. perception and body movement (Lakoff, 1987). Experiences such as up and down, centre and periphery, front and back, and inside and outside are conceptualised through schemata, which are conceptualisations of recurring, dynamic patterns of our perceptual interactions and motor programs. Schemata give coherence and structure to our experiences. The up-down schema, for instance, emerges from our experience with gravity and therefore we understand directly what verticality means. Several other schemata, such as the container schema or the balance schema, are conceptual structures grounded in bodily experience, too and can be understood directly. These schemata shape our conceptual understanding not only in everyday life but also in science. The well-understood structures of the schemata as a source domain are projected onto the abstract scientific target domains. Thus, scientific understanding, as abstract it may be, is ultimately grounded in embodied conceptions.

Obviously, conceptions of the climate change are abstract and thus indirectly embodied. We cannot experience climate change directly. Thus, its principles must be thought of in an imaginative way. Therefore this theoretical framework of experientialism leads us to the following research questions: Which embodied conceptions are deployed as source domains for students' and scientists' conceptions of the greenhouse effect? How can educationally reconstructed learning activities foster an accurate understanding of climate change?

## 3. The model of educational reconstruction as a research programme

The MER as a research program identifies and interrelates three relevant research tasks of subject matter education: (a) clarification of science content, (b) investigation into students' perspectives, and (c) analysis, design and evaluation of learning environments. Clarification of science content draws on qualitative content analysis of reliable sources like leading textbooks on the topic under inspection. The aim is to clarify the specific science content structure as constituted by the related conceptions from an educational point of view.

A critical analysis is necessary because academic textbooks address experts and present knowledge in an abstract and condensed manner that is not accessible for novice learners. We even find terms denoting obsolete thought. Investigation into students' perspectives aims at pre-instructional conceptions and conceptual development, primarily. Analysis, design and evaluation of learning environments refer to instructional materials, learning situations, and teaching and learning sequences. The design is lead by learning capabilities of the students on the one hand and clarification of science content on the other hand (Kattmann, Duit, Gropengießer, & Komorek, 1997; Duit, Gropengießer, & Kattmann, 2005; Duit et al., 2012).

In the educational reconstruction of climate change, scientists and students' conceptions are correlated to design effective teaching and learning activities (see figure 1).

We extracted scientists' conceptions (1) from various scientific textbooks and the IV<sup>th</sup> Assessment-Report of the Intergovernmental Panel on Climate Change, IPCC (2007). Students' conceptions (2) of global warming were sampled in a reanalysis of 24 empirical studies on everyday concepts of global warming (for the whole list see Niebert, 2010), our own interview study (n=11, 18 years, 5 female, 6 male) and during our teaching experiments (n=24, 18 years, 11 female, 13 male). All students attended secondary schools in northern Germany and had no prior instruction in climate change. On the basis of our analysis of students' and scientists' conceptions, we set up teaching guidelines (3a) and learning environments that operationalize the teaching guidelines (3b). The learning environments were evaluated in ten teaching experiments (3c). In our teaching experiments, which lasted approximately 65-90 min, we examined learning processes in small groups of two or three students.

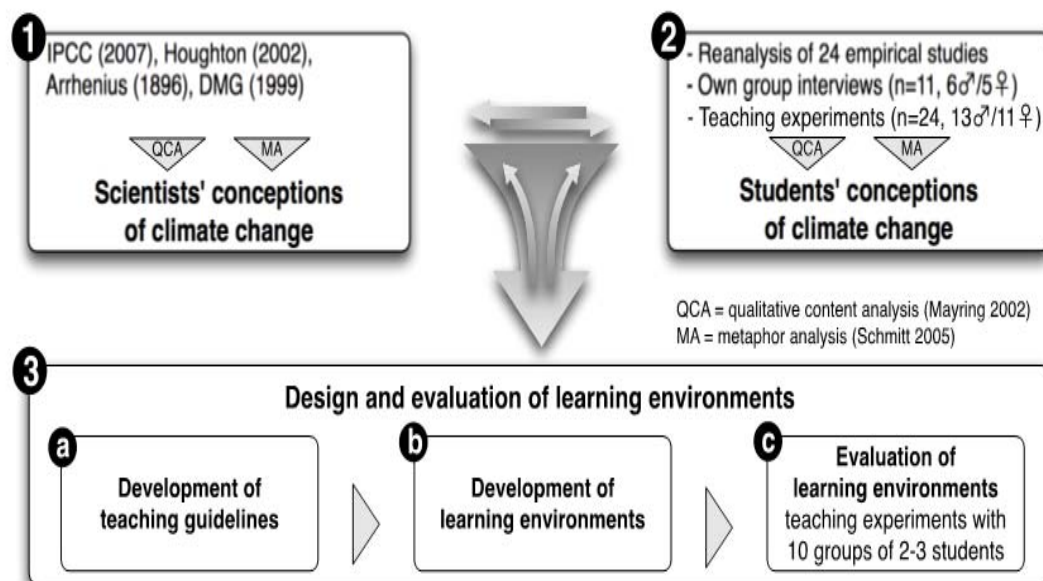


Figure 1: Research design derived from the model of educational reconstruction

Figure 1 points to the fundamental interaction between the three components of the Model of Educational Reconstruction. However, the three components do not strictly follow upon another but influence each other mutually. Consequently the procedure must be conducted step by step recursively. In practice, a complex step by step process occurs. Figure 2 presents this process in a still idealized and by no means obligatory succession.

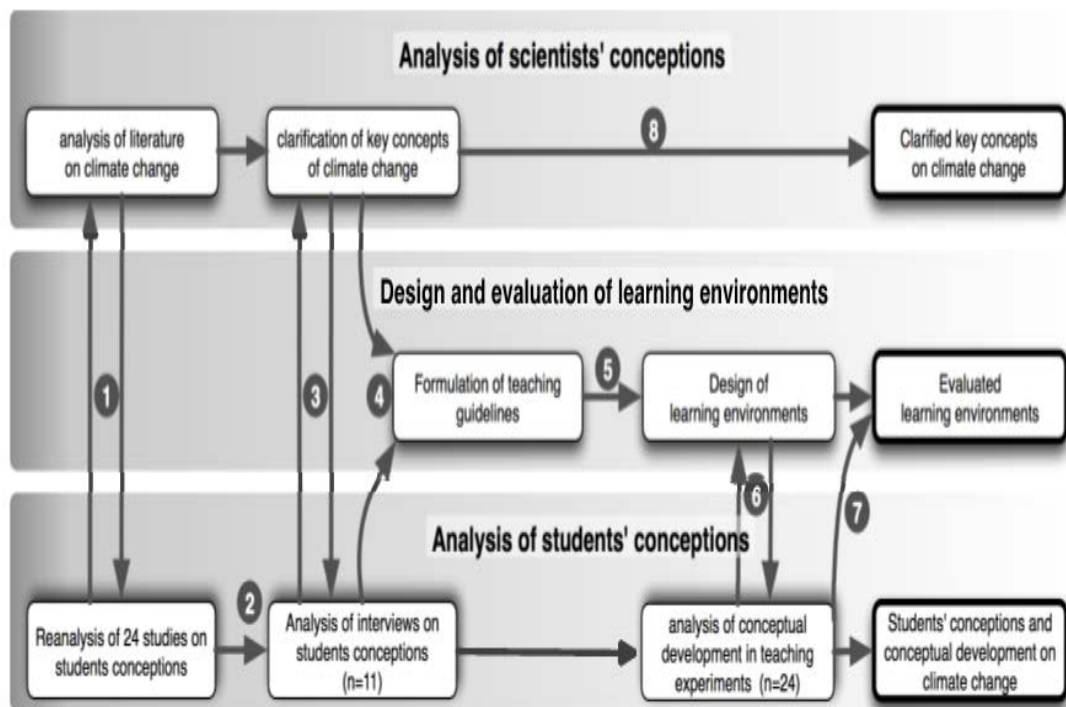


Figure 2: Idealized process of actual research progress of the educational reconstruction of climate change

Our research started with a parallel analysis of scientists' conceptions and students' conceptions as reported in literature (1). After mutually relating them to each other, a deepened analysis of students' conceptions in an interview study followed (2). We again related these conceptions to the scientists' conceptions (3) and took the results of this for the development of teaching guidelines (4). These teaching guidelines were operationalized in learning environments (5). In our study we additionally probed these learning environments in a formative evaluation by teaching experiments (6). Based on these analyses our research resulted in empirically evaluated learning environments and the description of students' conceptions and their conceptual development in working with these learning environments (7). Additionally we gained clarified key concepts relevant for teaching climate change (8).

In our study we analysed students' and scientists' conceptions by two different methods: In the course of qualitative content analysis (QCA), we developed categories in the following steps: (a) transcription of the interviews and editing the texts to improve readability, (b) rearrangement of statements by content, (c) interpretation of the statements aiming at the underlying conceptions, and (d) revision and final formulation of the categories. The metaphor analysis (MA) provides the basis for our interpretation of the conceptions from the perspective of experientialism. In our study, we identified a metaphor by a term or sequence that has or may have more than one meaning. In the first step, we identified all metaphors in the material. Secondly we chose the metaphors that were crucial for the understanding of climate change. Subsequently, we arranged all metaphors with the same source and target domains and thirdly described the metaphorical patterns used by the students and scientists. The results of the metaphor analysis were integrated into the interpretation of the conceptions during qualitative content analysis.

To assure the quality of the data analysis, all data were externally and consensually validated (Steinke, 2004) by discussion in our working group and cross-checked with other studies in the field. The article's first author conducted the teaching experiments and the interviews.

#### 4. Students' and scientists' conceptions of climate change

The conceptions of students and scientists on climate change presented in the following section are a selection of data. A more detailed presentation can be found in Niebert (2010).

##### The scientists' perspective

In 1896, Svante Arrhenius was the first to describe the effects of rising CO<sub>2</sub> concentrations on the climate. Since the United Nation's Intergovernmental Panel on Climate Change began publishing its assessment reports, research on climate change has become a major field in climate research. Scientists relate global warming to a change in the earth's radiation budget due to an intensified greenhouse effect. To explain the greenhouse effect, scientists refer to the container schema (cf. figure 3):

*"The solar radiation coming in is balanced by thermal radiation leaving the top of the atmosphere"* (Houghton, 2002, p. 257).

*"[...] incoming solar radiation and outgoing infrared (thermal) radiation [...]"* (IPCC, 2007, p. 136).

To interpret these conceptions, which are grounded in the experience-based container-schema, we analysed the structure of this schema to get a deeper understanding of the scientists' understanding of the greenhouse effect.

The container schema is based on the experience that our body is a container with a sharp border between inside and outside crossed by inputs and outputs (Johnson, 1987). The schema is structured by the elements "inside", "boundary", "outside" and "content".

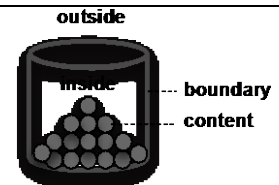


Figure 3: The container schema

Using the container schema, the atmosphere is conceptualised as a container to describe the flows of radiation between the inside and the outside. Additionally, a balance schema is used to describe equilibrium between the in- and outflows. With the conception *Atmosphere is a Container* the surface of the earth is used as lower boundary and an outward boundary is conceived at convenient heights where changes take place, e.g. the tropopause. The interior of the container consists of gases. The outward boundary is drawn to describe and quantify the energy flows between the atmosphere and space. The surface of the earth is conceptualised as the lower boundary of the container, which is crossed by energy and gases:

*The atmosphere of a planet is a gaseous envelope" [...]* (Houghton, 2002 p. 1)

*"Movements of carbon dioxide into and out of the atmosphere [...]"* (Houghton, 2002 p. 252)

The greenhouse gases, such as CO<sub>2</sub>, are responsible for the warming of the atmosphere:

*“The greenhouse effect [occurs in an] atmosphere that is more transparent to solar radiation than to infrared radiation. [IR-radiation] emitted by the planetary surface is absorbed by greenhouse gases. [...] If greenhouse*

(Houghton, 2002 p. 3)

*gases are increasing, this is leading to an enhanced greenhouse effect.”*

(Houghton, 2002 p. 255)

The conceptions of the greenhouse effect are based on two different elements enacting with the “container atmosphere”: radiation and CO<sub>2</sub>. Scientists regard radiation as electromagnetic energy, which has various wavelengths and related frequencies in a continuous spectrum. A relevant distinction in solar radiation is drawn between visible light (the short-wave section of the spectrum) and heat (infrared radiation). The visible light is absorbed by the earth’s surface and reemitted as infrared radiation. Visible light passes CO<sub>2</sub> unaffected, but infrared radiation interacts with CO<sub>2</sub>, raising its temperature. Rising CO<sub>2</sub> levels in the atmosphere absorb more infrared radiation in the atmosphere. The more CO<sub>2</sub> is in the atmosphere, the more radiation is absorbed. We call this conception *Warming by Greenhouse Atmosphere* (c.f. figure 4).

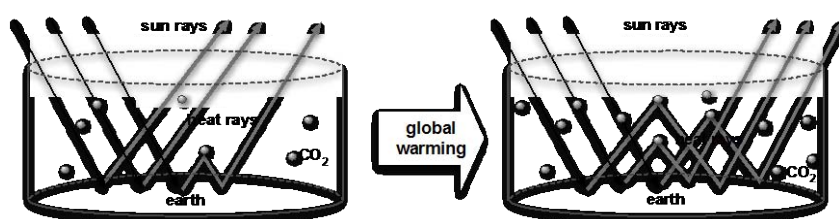


Figure 4: The scientists’ perspective - Warming by Greenhouse Atmosphere

#### Students’ conceptions: Warming by Holes in the Ozone Layer

In the introduction, we presented Emily’s conception of a warming earth by a hole in the ozone layer. For a broader understanding of this conception, we give two more examples of students holding this conception:

*“CO<sub>2</sub> destroys the ozone layer. Radiation coming from the sun passes into the atmosphere through the layer and heats up the earth” (Detlef, 18 yrs.).*

*“The ozone hole is getting bigger, because of more industrial emissions of CO<sub>2</sub>. CO<sub>2</sub> attacks the ozone layer and thus more sunrays enter the atmosphere and warm the earth” (Nanni, 18 yrs.).*

With this conception, students imagine the mechanisms causing global warming as follows. Normally, the ozone layer reflects some sunrays back into space. CO<sub>2</sub> causes a hole in the ozone layer, sunrays penetrate the layer through the hole and warm the earth.

In our study, 15 of 22 students expressed the conception that more sunrays pass through a hole in the *atmospheric protection shield of the “ozone layer”*. Metaphor analysis indicates students’ use of the container schema to describe the mechanisms of global warming. Terms such as *“passes into the atmosphere”, “through the layer”* or *“sunrays enter the atmosphere”*, indicate that the atmosphere is imagined as a container with the ozone layer as a shielding boundary. In the students’ conceptions, devastating qualities are attributed to CO<sub>2</sub>: it *“attacks”, “destroys”* or *“bites”*. With anthropomorphisms like these, students strive to grasp the idea of how a hole can get into the “ozone layer” atmospheric protection shield.

Students using this conception do not distinguish between visible light (short-wave radiation) and heat (long-wave radiation). From an experientialist point of view, this phenomenon is not surprising because we experience the sunrays as both bright and warming. In our everyday life, we are not aware of the absorption of visible light by our skin, the resulting increased movement of molecules in our body that leads to warming and the emission of heat over the body's surface. What we recognise is just: We feel warm if the sun shines down on us. Thus, it is not surprising that the students hold the conception that the more sunrays there are, the warmer it is (figure 5).

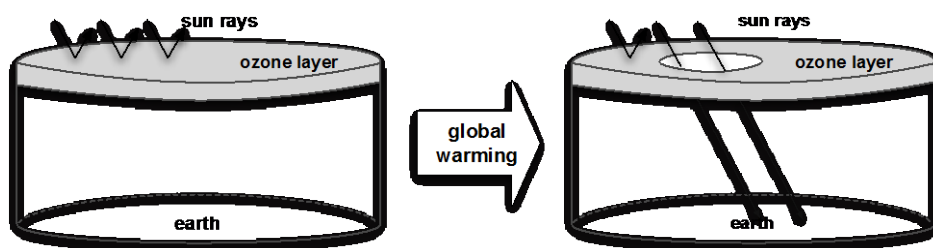


Figure 5: Students' conception - Warming Ozone Hole

The hybridisation of the ozone problem with the greenhouse effect is a well-established finding in science education research (e.g., Ekborg & Areskoug, 2006, Koulaidis & Christidou, 1999). The concept of a perforated *atmospheric protection shield* leads to a simple idea: *the atmosphere warms up because more heat gets in.*

#### Students' conception: Warming by Greenhouse Effect

In our interviews with students about global warming, we identified another conception that seems quite similar to the concepts expressed by the scientists: warming by greenhouse effect. *"The sunrays are absorbed by the earth's surface. [...] The heat is released again, but a layer of greenhouse gases hinders the heat going back into space. So the heat stays in the atmosphere"* (Claudia, 18 yrs.).

*"A layer of CO<sub>2</sub> hinders the visible light coming to earth from going back into space again and reflects the light back to earth. So it gets warmer in the atmosphere"* (Jürgen, 18 yrs).

In this conception, the greenhouse gases (mainly CO<sub>2</sub>) form a special layer in the atmosphere, which is permeable for sunrays but nearly impermeable for the radiation coming from the earth. This conception is also based on the container schema ("*into space*", "*in the atmosphere*"). The conception is similar to the greenhouse effect communicated in the media or in schoolbooks. The central element of this conception is a layer of greenhouse gases that acts as a barrier that becomes thicker and thus less permeable. Therefore, the heat radiation is captured under the greenhouse gas layer in the atmosphere. The basic idea is that *the earth warms up because less heat gets out* or, even more simply, *warming by less output* (figure 6). In contrast to the scientists who claim that evenly distributed CO<sub>2</sub> captures the heat in the atmosphere, in students' conception, the CO<sub>2</sub> is not evenly distributed in the atmosphere but forms the upper layer of the atmosphere.



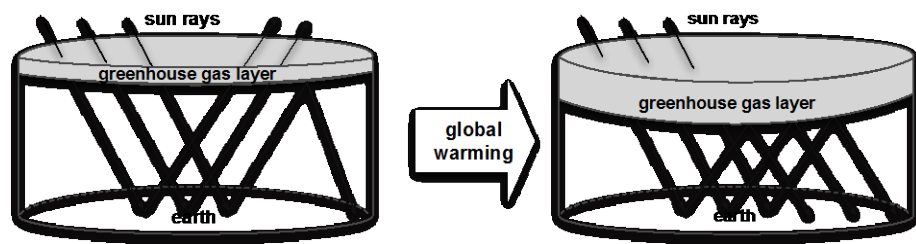


Figure 6: Students' conception - Warming by Greenhouse Effect

## 5. Bringing together students' and scientists' conceptions on global warming

The commonalities and differences between the conceptions are compared in table 1:

Table 1: Conceptions of the processes of global warming

	Everyday Conceptions	Scientific Conception	
Container	<p><b>Warming by Ozone Hole</b></p> <p>"CO<sub>2</sub> makes a hole into the ozone-layer. More sun rays enter the atmosphere and the earth warms up"</p>	<p><b>Warming by Greenhouse Effect</b></p> <p>"Sun rays come through the CO<sub>2</sub>-layer into the atmosphere. They are transformed into heat and captured"</p>	<p><b>Warming by Greenhouse Atmosphere</b></p> <p>"CO<sub>2</sub> is evenly distributed in the atmosphere. More CO<sub>2</sub> shifts the radiative equilibrium."</p>
	Ozone is boundary	CO <sub>2</sub> is boundary	CO <sub>2</sub> is content
	CO <sub>2</sub> destroys boundary	CO <sub>2</sub> is permeable one way only	CO <sub>2</sub> is impermeable for heat rays

The comparison shows different mappings of the container schema to the target domain of climate change. In all conceptions, the atmosphere is understood as a container. However, students and scientists map the container schema differently on the atmosphere, depending whether the container's boundary is thought to be made of a CO<sub>2</sub> layer (greenhouse effect), an ozone layer (ozone hole) or just assumed (scientists). CO<sub>2</sub> is conceptualised in different roles in relation to the container: whether it destroys the container's border (ozone hole), is permeable one way (greenhouse effect) or is permeable for sunrays but impermeable for infrared rays (scientists). From an experientialist's perspective, we base learning about climate change on the principle of "reconstructing the container" and thus on the following teaching guidelines.

Students should :

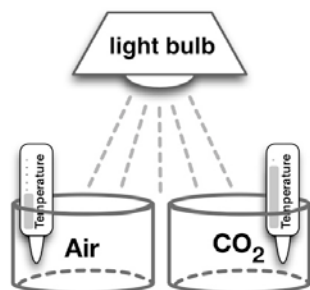
- reflect on the border of the containers: is it an ozone layer, a CO<sub>2</sub> layer or just assumed?
- reflect on the role of the CO<sub>2</sub>: does it form the border of the container or is it the content?  
Does it destroy the border or trap heat?

The next section shows how learning environments can facilitate this reflection.

## 6. Design of learning environments and evaluation in teaching experiments

To analyse whether and how learning environments influence students' conceptions, we evaluated the learning environments in teaching experiments. Teaching experiments (Riemeier & Gropengießer, 2008; Steffe & D'Ambrosio, 1996) provide empirical opportunities to combine interview situations (investigational aspect) with teaching (interventional aspect). The analysis of our teaching experiments provided information about the students' pre-instructional conceptions and their development in the course of instruction. The role of the researcher is twofold: to identify students' conceptions as an interviewer and to organise learning activities as a teacher depending on students' conceptions. In the teaching experiments, students were offered learning environments matching their conceptions. Each teaching experiment was carried out by the first author in small groups of two or three students on the premises of the Leibniz Universität Hannover. The teaching experiments were videotaped for a process-based analysis of students' conceptual development.

As we have shown before, the understanding of the greenhouse effect is based on the container schema. Differences between a scientific understanding and everyday conceptions originate from different ways of mapping the structures of the container to the structures of the atmosphere. Thus, we designed learning environments that helped students to reflect on the mapping of the container schema for climate change. Two of our learning environments are presented and evaluated in this paper. The students carried out an experiment in that the container schema was materialised as a glass box and asked students to analogue the box and the atmosphere (figure 7).



Two glass boxes were filled with CO<sub>2</sub> and air. Both boxes had an open top, black bottoms and were irradiated with a strong light bulb (200 W). The temperature was measured. It rose in the box filled with CO<sub>2</sub> about 2 degrees centigrade higher than in the box filled with air. Students were asked to interpret the phenomenon.

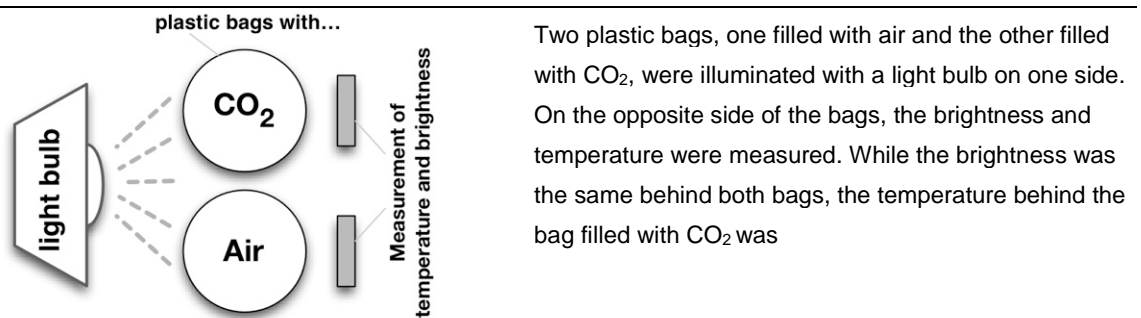
Figure 7: Design of the learning activity intended to reconstruct the container

In one of our teaching experiments, the student Max expresses his conception based on working on the learning environment:

*“Initially, we said that it gets warmer because CO<sub>2</sub> destroys the ozone layer. But here we have no ozone layer and no ozone hole. But the container with the CO<sub>2</sub> heats up for two degrees anyway. How is the CO<sub>2</sub> doing this? I don’t know.” (Max)*

Initially, Max holds the conception that climate change is due to an ozone hole caused by CO<sub>2</sub>. During the experiment, he recognises a heating of the container with the CO<sub>2</sub> and notes that there is no ozone layer that caps the container. Thus, his observations lead him into a cognitive conflict with his initial conception.

He still blames CO<sub>2</sub> for the heating, but he has no idea of the mechanism. Thus, he carried out another experiment that focused on the role of CO<sub>2</sub> in global warming (figure 8).



Two plastic bags, one filled with air and the other filled with CO<sub>2</sub>, were illuminated with a light bulb on one side. On the opposite side of the bags, the brightness and temperature were measured. While the brightness was the same behind both bags, the temperature behind the bag filled with CO<sub>2</sub> was

1.5 °C lower than behind the plastic bag because CO<sub>2</sub> absorbs the heat.

Figure 8: Design of the learning activity intended to reflect on the role of the CO<sub>2</sub>

This experiment helps Max to recognise the relevant properties of CO<sub>2</sub> and thus the content of the container.

*“Despite the content, both bags are treated equal. The visible light goes through the bags. Behind the bag with the air, it is warmer than behind the bag with CO<sub>2</sub>. Thus, CO<sub>2</sub> will absorb the heat. The heat stays in the bag. [...] So my theory is: the CO<sub>2</sub> in the atmosphere captures the heat and thus it gets warmer” (Max).*

Max describes both bags as transparent for visible light. He also recognises that it is warmer behind the bag filled with air than behind the bag filled with CO<sub>2</sub>. He interprets his observations in the intended way: CO<sub>2</sub> is transparent for light and not transparent for heat, while air is transparent for both. After interpreting the experiment, he relates his hypotheses to the atmosphere and relates global warming to the capturing of heat due to CO<sub>2</sub>.

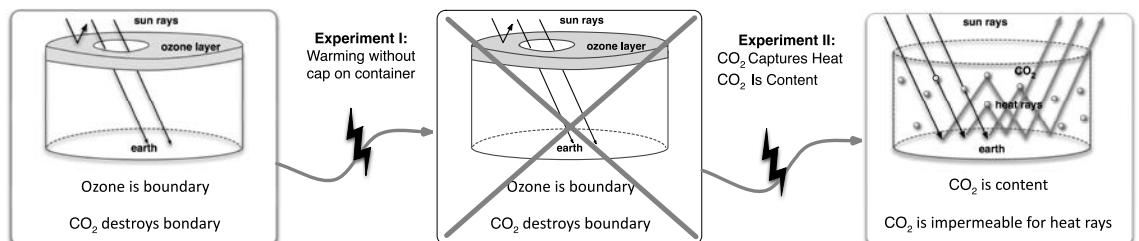


Figure 9: Max's thinking pathway: reconstructing the container

Inspired by both experiments, Max reconstructs his mapping of the container schema to the atmosphere. While a hole in the container's boundary is initially blamed for letting the heat into the container, the first experiment leads to a cognitive conflict, and Max subsequently rejects this conception (figure 9). The second experiment allows Max to experience the effect of CO<sub>2</sub> in global warming on a small scale. Animated by this experiment, he develops the idea that CO<sub>2</sub> as the container's content ("the CO<sub>2</sub> in the atmosphere") is causing global warming by trapping the heat. Thus, he reconstructs not only the role of the container's boundary but also the role of the content, from disrupting (causing the hole) to capturing (trapping the heat).

## 7. Discussion and conclusions

So far, we have analysed conceptions on global warming in scientific textbooks and research reports, on the one hand, and interview data and video data of learning situations, on the other hand. We paid particular attention to the experiential basis of understanding. Remarkably, students and scientists ground their understanding at the level of schemata on similar experiences. However, students and scientists differ considerably in the way the mapping from the source domain to the target domain is conducted. With regard to the experiential basis of the conceptions, we designed learning environments. Through evaluation in teaching experiments, we could track students' learning pathways.

Because both students and scientists refer to the same schemata as the source domain for their conceptions of climate change, learning about global warming can be facilitated by a reflection on the schemata. Investigating a CO<sub>2</sub>-filled glass box is a materialised representation of cognitive schemata employed in understanding climate change. By working with these representations, students re-experience the inherent structure of the schemata and reflect on how they employ it in their effort to understand the phenomenon. This re-experiencing and reflecting helps students to understand the complex and abstract phenomenon of climate change. To this end, students need to work with learning environments that illuminate the schemata they employ in their endeavour to understand. Awareness of the schemata that shape conceptual understanding enables teachers to choose effective representations and to design learning environments that foster an understanding of science.

### The MER as a research programme for science education

The model of educational reconstruction (MER) provides a broadly conceived approach for subject-matter education research (Duit et al. 2012; Duit, et al., 2005; Kattmann, et al., 1997). It provides a frame for research to design teaching and learning sequences that are relevant for improving instructional practice. The MER integrates the perspectives of students and scientists in order to design learning environments. What we call educational reconstruction of the learning environment on the greenhouse effect may be viewed from the American Curriculum tradition as well founded segment of a teacher's content specific pedagogical knowledge (PCK) (Shulman 1987, 8).

The MER also shares common features with Developmental Research (Lijnse 1995). Lijnse proposed a cyclical process of small-scale curriculum development coupled with classroom research on teaching and learning in order to design "didactical structures". Developmental research aims at describing, justifying and understanding content specific teaching and learning, thus developing content specific theories. Björn Andersson and Anita Wallin (2006) state two objectives for the design and validation of topic oriented teaching-learning sequences. One concerns the designed artifacts like teacher guides and student materials. The other one aims at the development of content oriented theories that they regard as an outcome of design research.

The growing family of educational research approaches, that have "the intend of producing new theories, artifacts and practices that account for and potentially impact learning and teaching in naturalistic settings" (Barab & Squire 2004) may be called *educational design research*. Related terms that often highlight the emphasis of the respective project are *design based research*, *design studies*, *design experiments*, *developmental research*, *formative research*, *formative evaluation*, *engineering research* etc. (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006, 4).

What connects and characterizes these educational design research approaches are certain features like (a) *usefulness* by linkage to practical needs as the MER is used to develop learning activities, (b) *theoretical orientation* by grounding in theory and developing, testing, and refining content oriented local theories, (c) *interaction of investigation and intervention* as the teaching experiments provide classroom oriented situations for interventions and research at the same time, (d) iterative design as a nonlinear, cyclical proceeding of design, evaluation, and revision as the process of the MER as presented in figure 1 is a recursive process, (e) *process oriented* with a focus on understanding and inventing and improving interventions (cf. van den Akker et al., 2006; Bell, 2004; Burkhardt & Schoenfeld, 2003; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003; Kelly, Lesh, & Baek, 2008; Plomp, 2009).

The MER shares these features and it enabled us in our study to conduct a structured analysis of conceptions on the greenhouse effect as well as a comprehensible design of learning environments by coordinating three closely interdependent aspects of research: (1) investigation into students' perspectives, (2) clarification and analysis of subject matter content and (3) design of learning environments. The accomplishments of the MER can be seen in identifying these three tasks that are at the core of subject matter education research and design and relating them in a productive way.

#### **Clarification of science content is mandatory for successful learning environments**

It is widely accepted by science educators that it is necessary to take the students' prior conceptions into consideration within the learning discourse. Therefore, the investigations of students' pre-instructional conceptions must be given serious attention with respect to their support of a conceptual development towards the scientific view (Duit & Treagust, 2003). We give equal attention to science subject matter issues. We regard science as created and conducted by humans and hold that a critical analysis of a particular science content from the standpoint of science education is necessary. The science content structure of the greenhouse effect found in university textbooks cannot be transferred directly into the content structure for instruction. The clarification of science content is a serious task for science educators. The MER is based on the premise that when teaching science, the science content structure of a certain domain (e.g., atmospheric energy budget) must be transformed or reconstructed into a content structure for instruction.

The analysis of scientists' conceptions draws on content analyses of leading textbooks and research reports. Taking students' pre-instructional conceptions into account contributes to a deeper understanding of the scientific content. Our parallel analyses of students' and scientists' conceptions on global warming were mutually beneficial for the investigation tasks. They sharpened our view for the similarities (same schemata) and the differences (different mappings) in everyday and science perspectives.

The design of learning environments is often misleadingly characterized as reduction of breadth, depth and difficulty of the science content. But this notion of pure simplifying misses the point that the science content has to be enriched and grounded in experiences as provided by the experiments on the interaction of radiation and CO<sub>2</sub> (see fig. 6 and fig. 7). While part of the content structure is simplified to make it comprehensible for students, it is also be enriched by relating it to the conceptual structure of the students' conceptions, thereby making it accessible to the students. We call this process the reconstruction of learning environments with regard to the learners.

It builds on our findings on students' perspectives, i.e. their potentialities and learning difficulties on the one hand and the (preliminary) results of clarification and analysis of subject matter content on the other hand. Both resources are regarded as equally important for the design of learning environments.

### **Educational Reconstruction is a recursive process**

The three tasks do not follow in a straightforward order. The MER research programme requires a recursive procedure. One can start with any task, but it is necessary to revise each task in the light of the preliminary results of the investigations within the other tasks. The cornerstone in designing learning environments within the MER is the teaching experiment. In the teaching experiment the interviewer acts as researcher and teacher at the same time. Wilbers and Duit (2001) describe the simultaneous role as beneficial for studies in science education, since the research situation resembles the authentic classroom.

The interviews during the various teaching experiments served as a means to evaluate the learning environments. In an iterative process of formative evaluation, the learning environments were improved, informed by the interplay of evidence and theory. This result enabled us to analyse why certain aspects of the learning environments foster or hinder conceptual understanding. The investigation of students' understanding with teaching experiments enabled us (1) to validate the conceptions we found in the re-analysis of published findings and in our own interviews and (2) to select adequate learning environments that address students' conceptions. The data from the teaching experiments demonstrate the impact of the learning activities on the students' learning about the greenhouse effect. Based on our process-oriented analysis, we were able to observe steps of conceptual development towards scientific understanding. This points to another fruitful research approach the MER shares some major features with. Learning progressions that are seen as "strategies for formulating and developing environments of learning that align curriculum, instruction and assessment" (Duschl, Maeng, & Sezen, 2011) focus on grows of knowledge over time.

The example of climate change as discussed in this paper is one investigation within the MER research programme. Others are conducted on topics like vision (Gropengießer, 1997), growth (Riemeier & Gropengießer, 2008), evolution (Zabel & Gropengiesser, 2011), or symbiosis (Gross & Gropengiesser, 2005). This demonstrates that the MER provides a framework for successful content oriented educational research that designs learning environments or learning sequences, evaluates or revises commercial media or learning environments, and, last not least, develops content-oriented theories of learning and teaching science. The MER frames both *research-based design* as well as *design-based research*.

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## Electronic Performance Support for Curriculum Materials Developers: A Design Research Project in Sub-Saharan Africa

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# 26. Electronic performance support for curriculum materials developers: A design research project in sub-Saharan Africa

Susan McKenney & Thomas Reeves

## Abstract

*Although teacher guides are, next to textbooks, among the most-used teacher resources worldwide, little empirical research has been conducted on how to support the developers of such guides in their complex task. Through a multi-year iterative process of analysis, design, evaluation, and revision, design research was conducted to gain insight into desirable characteristics of an electronic performance support system for curriculum materials developers in southern Africa. From a practical standpoint, this study yielded positive experiences for the participants and a software tool that is not only valid and practical, but also has the potential to positively impact users if implemented well. From a scientific standpoint, design principles were generated, tested and refined for key system characteristics, specifically: content, support and interface. The design study flanking evolution of the tool helped (re)shape each prototype, and to track effects on both the professional learning of the materials developers and the quality of the curriculum materials made. Because long-term, high-quality design studies in the field of education are rare, this chapter focuses on the research approach, and its affordances for contributing to theory-development while also capturing and speaking to the needs of practitioners.*

## 1. Introduction to the problem

In the last few decades, the concept of Teacher Resource Centers (TRCs) has become widely accepted across southern Africa as an essential ingredient of a professional support structure for teachers and schools (Hoppers, 1998). Among other activities, TRCs often provide the context in which resource center staff members collaborate with local teachers to develop lesson materials that exemplify specific elements of an innovative curriculum. In such a context, curriculum development and teacher professional development can be viewed as two mutually enhancing processes. As Jonassen and Reeves (1996) put it, "...the people who seem to learn the most from the systematic design of instructional materials are the designers themselves" (p. 695). This study set out to explore how a computer-based tool might be able to contribute to and even enhance the synergy that exists between curriculum development and professional development at a very natural crossroads... the creation of exemplary lesson materials.

Another goal of this study was to explore how to refine emerging theories that are used to support curriculum development, e.g., collaborative and reflective inquiry (Bray, Lee, Smith, & Yorks, 2000). Educational design research (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006) was applied in this study because of its twin focus on practical solutions and theoretical knowledge refinement. Design research studies emphasize the whole cycle of scientific inquiry, often involving sub-studies in cycles throughout the stages of problem identification, hypothesis (re)forming, solution development and testing. Design studies require interaction and collaboration among researchers, teachers, and other stakeholders.

According to Barab and Squire (2004), design research is “a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings” (p. 2). Design research has been gaining momentum as a distinct genre of educational research over the last two decades. In special issues of highly respected journals, the need for attention to be given to design research was demonstrated: *Educational Researcher* (2003, 31(1)), *Journal of the Learning Sciences* (2004, 13(1)); *Educational Psychologist* (2004, 39(4)). Books devoted to the topic examine design research conceptualization (van den Akker et al., 2006) as well as methodological options (Kelly, Lesh, & Baek, 2008; McKenney & Reeves, 2012; Reinking & Bradley, 2008).

Several different models for design research have appeared in the literature. Some are more conceptual, and have been used to help describe differing sequences of steps in the design research process (cf. Ejersbo et al., 2008). Others emphasize a flexible but clear process, along with varying degrees of conceptual, or substantive, support. Reeves (2006) offered a model that highlights the process but is less detailed from a substantive standpoint; whereas that of McKenney, van den Akker and Nieveen (2006) tends to be more focused on core concepts and less on the process. A model put forth by Bannan-Ritland and Baek (2008) pays attention to both process and concepts, but has not been widely adopted. Based on an analysis of existing models, McKenney and Reeves (2012) produced a multi-phase model that attempts to adequately represent the dynamic nature of design research, while accounting for large degrees of methodological freedom (see Figure 1).

The trapezoid at the top of the model represents the steadily increasing interaction with practice through implementation and spread of the resultant intervention and understanding that emerge from design research. The two dark boxes on the right side of the model illustrate the twin outcomes of design research. The three squares in the model represent the three major phases of inquiry and development which are central to design research. The first phase (left) represents the interactive give-and-take between analysis and exploration, typically seen during the early stage of a design research study. The second box represents the interactive processes of design and construction that yield the prototype interventions which are tested and refined during the third phase: evaluation and reflection. Most design research projects will repeat each of the interactive processes represented both within and across these boxes several times. (Indeed, the study described in this contribution also involved multiple micro-cycles within each main phase of analysis and exploration, design and construction and evaluation and reflection.) In so doing, slight refinements can be made. For example, it is common for the focus of evaluation and reflection to shift as insights and interventions mature. Earlier alpha-style evaluations tend to center on the internal structure of interventions (validity); during beta testing, use in context (practicality) receives more attention; and once interventions stabilize and are used under representative circumstances, more robust gamma testing can take place (effectiveness).

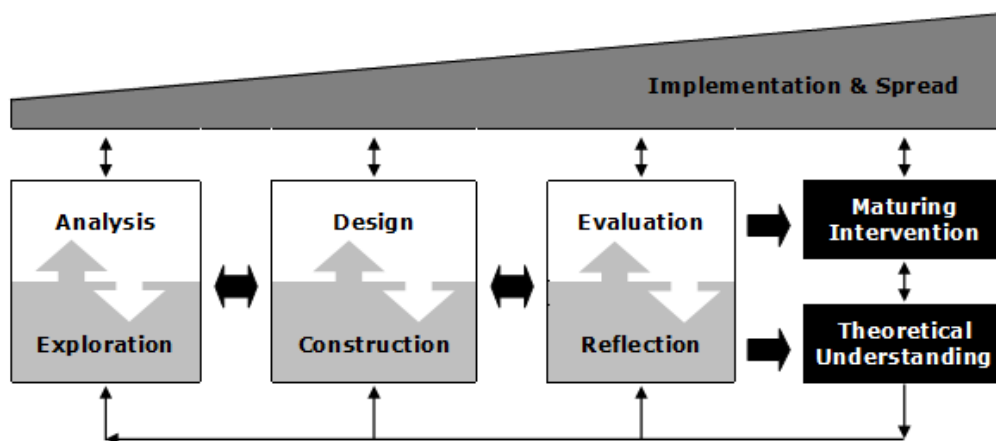


Figure 1: Multi-phase model for educational design research (McKenney & Reeves, 2012)

The aforementioned literature on design research have been pivotal in garnering increasing support for a research approach now considered by many scholars to be a viable route to increasing the relevance of educational research. However, legitimate questions about the ultimate value of educational design research have been raised (cf. Anderson & Shattuck, 2012). Clearly, the evidence supporting this approach will be enhanced if the current body of literature contained more in-depth examples of long-term, high-quality design research. More examples demonstrating how this approach can be applied in the context of developing countries would be especially valuable. This paper describes each aspect in the multi-phase model (Figure 1) and illustrates its elements through a 4-year study on supporting curriculum materials developers in southern Africa.

## 2. Development of conceptual framework

Many tools have been developed to provide support to curriculum developers, but at the time of this study (McKenney, 2001), none were available that specifically targeted the kind of work carried out by teacher-designers working in Teacher Resource Centers (TRCs) in southern Africa. In addition, very little guidance was available in scientific literature that could underpin such work, by giving answers to questions like: What would a scientifically valid tool - one that contained state of the art knowledge and was internally consistent - look like? How could it be made practical for this context? What features would be necessary for it to yield high quality materials and offer learning experiences to the users?

Therefore, the Computer Assisted Curriculum Analysis, Design & Evaluation for Science Education in Africa (Cascade-Sea) program was developed and design research was conducted to address (a) the practical problem of the need for support in TRCs; and (b) develop theoretical understanding that could serve the creation of similar tools. This study was guided by the following main research question: *What are the characteristics of a valid and practical support tool that has the potential to impact the performance of (resource) teachers in the creation of exemplary lesson materials for secondary level science and mathematics education in southern Africa?* A conceptual model illustrating the relationships between the main concepts in this study are illustrated in Figure 2.



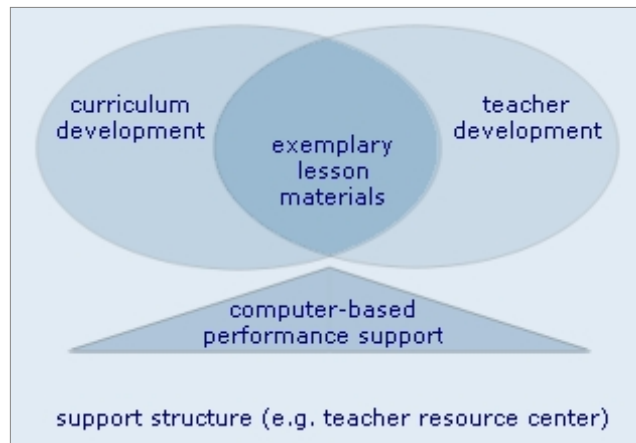


Figure 2: Conceptual model of the Cascade-Sea study

### 3. Design and development stages

#### Approach

At the beginning of the study and throughout its evolution, guidance was sought from literature relating to curriculum development, teacher professional development, exemplary materials, existing support structures (such as TRCs) and computer-based performance support. Insights from relevant literature along these thematic lines helped to shape the structure of the study as well as the Cascade-Sea program itself. These ideas were articulated in the form of tenets that served to guide research and development activities. These tenets pertain to the following topics:

- **Local relevance:** any educational innovation must be carefully examined and, if necessary, (re)tailored for the context and culture in which it will be implemented.
- **Collaboration:** design and development activities (related to an innovation) must be conducted in *collaboration with* and not *for* those involved.
- **Authenticity:** efforts must be based on a working knowledge of the target setting and, where possible, research and development should be conducted in naturally occurring test beds.
- **Mutual benefit:** a skillful attempt should be made to combine research activities with meaningful experiences for the participants.
- **Continuous (re)analysis:** careful and regular analysis of the risks and benefits of the innovation should be conducted in the light of the target setting, with design and development decisions being taken accordingly.

#### Three phases

The design study on supporting curriculum materials developers took place in several phases, as shown in the multi-phase model (Figure 1). As described above, the model features three boxes, or phases, in which research activities take place: analysis/exploration, design/construction and evaluation/reflection. The interaction between design/construction and the other phases demonstrate how empirical findings feed into design. In this study, two iterations (also known as micro-cycles of design research) took place in the first phase, four iterations in the second phase, and two in the third phase. Within each iteration, multiple data collection activities took place in which participants cooperated to yield multiple types of data (e.g., by responding in a focus group to a demonstration and then, after a hands-on session, giving feedback through a questionnaire).

Throughout the study, four main strategies were used:

- *Developer screening*: Developers 'walk through' design documents and critically reflect
- *Expert appraisal*: Experts provide feedback e.g., on working prototypes or user products
- *Micro evaluation*: Prototypes are used under near-to-normal circumstances
- *Tryout*: Prototypes are used by the target group in the target setting under natural conditions.

Figure 3 shows the approaches (top of box) main data sources (bottom of box) used in each of the three phases.

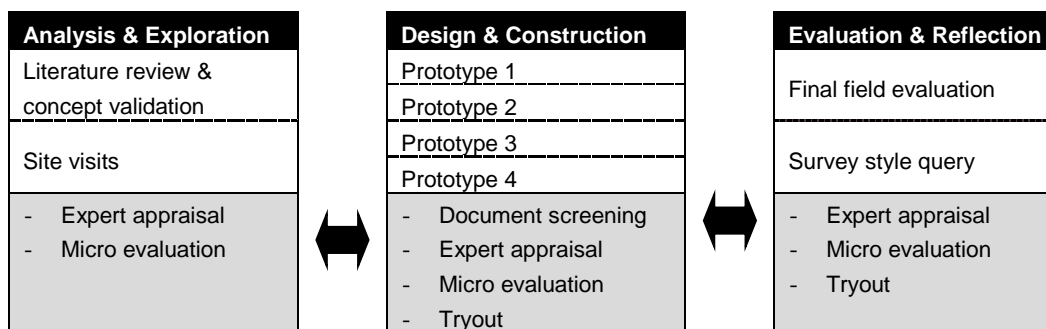


Figure 3: Methods for data collection in each phase of the study

Detailed descriptions of each phase have been reported elsewhere (McKenney, 2001).

Toward understanding the research approach, and its affordances for contributing to theory-development while also capturing and speaking to the needs of practitioners, the basic process is briefly described here.

The primary goal of the analysis and exploration phase was to obtain a working knowledge of the target setting, user group and areas in which a support tool may be put to work. Previous design research focused on computer-based support for curriculum developers (Nieveen, 1997) had yielded a tool for formative evaluation that served as a springboard throughout this study, especially in the analysis stage. This phase consisted of two main cycles. Beginning with a study of relevant literature along with interviews with experts and professional curriculum developers, the analysis and exploration phase culminated in visitations to various curriculum development/teacher development programs in southern Africa. During the visitations, an English version of the CASCADE tool (originally developed in Dutch) as well as initial analysis findings were presented to expert and user groups who were involved in materials development as part of an inservice scenario. Members of these groups offered feedback in the form of initial design ideas, as well as tentative suggestions for future cooperative activities.

The design and construction phase relied heavily on the cooperation of both expert and user groups as well as other institutions and individuals. Through iterative cycles of design, development and prototype evaluation, the Cascade-Sea tool evolved. The main criteria upon which these (four) prototypes were evaluated during the design and development phase were validity (state-of-the-art knowledge and internal consistency) and practicality (use in context based on Doyle and Ponder's conceptualization including: instrumentality; congruence with existing beliefs and cost in relation to anticipated benefits).

The evaluation and reflection phase of this study explored the potential impact of the Cascade-Sea system in terms of (potential) contributions to teacher development and curriculum development as a result of its use. This phase may best be described as 'semi-summative' in nature. This is because during this phase evaluative activities mainly possessed characteristics of summative evaluation (in particular, the aim), but maintained a number of formative evaluation elements as well. Results from this phase were used to assess CASCADE-SEA's effectiveness in terms of its potential to positively impact (a) the performance of its users with regard to the quality of materials they would create; and (b) professional development of its users.

### **Sampling**

The study described in this chapter was primarily conducted through successive evaluation of four computer-based prototypes. Each prototype was evaluated with a number of groups (ranging from two to six different groups per prototype). While chain referral (or snowball) sampling best characterizes the strategy used for making sampling decisions with regard to each individual group, stratified purposeful sampling was used to facilitate comparisons between types of groups. The two types of participants in this study were user groups and expert groups. The user group included preservice teachers (this group became involved as a result of the study's emergent nature and the aforementioned chain referral strategy), inservice teachers (emphasizing resource or facilitator teachers) and curriculum developers. The expert groups consisted of science education experts, curriculum development experts and experts in the area of computer-based performance support. Earlier stages of the study (focused more on understanding validity-related criteria) involved a higher degree of experts than those in later stages, which examined the practicality and potential impact of the Cascade-sea program. In such later stages, user groups played a more prominent role in evaluation activities. In total, 510 participants (see also Table 1, in the following section) contributed to this study.

"Choices of informants, episodes, and interactions are being driven by a conceptual question, not by a concern for 'representativeness.' To get to the construct, we need to see different instances of it, at different places, with different people," (Miles & Huberman, 1994, p. 29). The structure of this study was shaped by the desire to explore many 'different instances' of participant perceptions. As a result, a wide variety of data collection activities was undertaken. Each time a data collection opportunity arose, usually through dialogue with (potential) participants, researcher/developers weighed off perceived costs (time, finances, etc.) with estimated benefits (e.g. depth and validity of prototype feedback), in accordance with the tenets that guided this study. Many activities were eventually conducted even when the perceived benefit was relatively low, because (as long as the related costs were also minimal), this was considered a low-risk method of exploring what types of 'different instances' would actually yield the most fruitful data. This kind of flexibility was built into the study, so that knowledge and findings from previous cycles could then be applied to subsequent ones. Further, consideration of participant suggestions, even with regard to data collection opportunities, was consistent with the relational approach as advocated through the foundational tenets. Table 3.3 in McKenney (2001) reconstructs the researcher's perceptions concerning the salience and the intensity of each micro-cycle for addressing the main research questions. A simplified version is presented here in Table 1, featuring the number of participants in each main cycle and a gradual shift from studying validity, then practicality and then impact potential.

Table 1: Cycle and data weight over time

Data collection over time		Validity		Practicality			Impact potential		N Participants*
Phase	Cycle	SAK	INC	INS	CON	COS	BQM	EPD	
Analysis & exploration	Literature review	High	Medium	Low	Low	Low			18
	Site visits	Low			Medium	Medium			54
Design & construction	Prototype 1	High	High	High	High	High			50
	Prototype 2	Medium		Low	High	Medium	Low	Low	63
	Prototype 3	Low	Medium	High	High	High	Low	Low	169
	Prototype 4		Low	High	High	High	Medium	Medium	140
Evaluation & reflection	Final evaluation	Low	Low	Medium	Medium	Medium	High	High	45
	Query	Low	Low	Medium	Medium	Medium	High	High	34

\* Some individuals participated in more than one cycle

**Legend**                      □ = None    ◻ = Low    ◼ = Medium    ◼ = High

V=Validity: SAK=state-of-the-art knowledge; INC=internal consistency

P=Practicality: INS=instrumentality; CON=congruency; COS=cost

I=Impact: BQM=better quality materials; EPD=enhances professional development

### Instrumentation

Instruments were developed to use along with each of the four strategies described above. While variation exists among like kinds of instruments, so do similarities. For example, various interview schemes were designed to gather information about the same aspects (internal consistency of the program interface, for example), while being used in different settings. In such a case, rather than develop completely new instruments, researchers often tailored existing ones. Additionally, instruments were improved wherever possible, based on insights acquired through previous uses. This approach resulted in 'instrument families' containing like kinds of instruments with related roots but also certain degrees of variation. As is common in educational design research, a mix of quantitative and qualitative methods was used. Six main families of instruments were used:

- Interview and walkthrough schemes
- Questionnaires
- Discussion guides
- Observation and demonstration schemes
- Logbooks
- Document analysis checklists

Instrument families were typically used with small groups of participants at a time (ranging from 3-12), but the specific procedures used during each of the 34 data collection activities did vary.

Table 2 presents an overview of the 108 times that instruments were administered during this study.

Table 2: Administration of instruments overview

Phase	Cycle	Interview & Walkthrough Schemes	Questionnaires	Discussion Guides	Observation & Demo Schemes	Logbooks	Document Analysis Checklists
A&E	An			1	3		
	SV	2	3	2			
D&C	P1	3		4	1		
	P2	1	1	1	2		1
	P3	5	19	6	7	3	3
	P4	4	10	4	5	1	1
E&R	FE		4	3	3	1	3
	Qu		1				

### Legend

LR	= Literature review and concept validation	IS	= Interview scheme
SV	= Site visits	W	= Walkthrough scheme
P1	= Prototype 1	Q	= Questionnaire
P2	= Prototype 2	DG	= Discussion guide
P3	= Prototype 3	O	= Observation scheme
P4	= Prototype 4	D	= Demonstration guide
FE	= Final evaluation	L	= Log book
Qu	= Query	DA	= Document analysis checklist

### Data analysis

To maximize the potential of the study's emergent design, data analyses were conducted after each data collection activity so as to inform the following ones (and again at the end of the study). Such repeated interim analysis is referred to as 'sequential analysis' by Miles and Huberman (1994) who commented as follows on the strength and weaknesses of this approach: Their "interim analyses strength is their exploratory, summarizing, sense-making character. Their potential weaknesses are superficiality, premature closure, and faulty data. These weaknesses may be avoided through intelligent critique from skeptical colleagues, feeding back into subsequent waves of data collection" (p. 84). In this study, the means used to conduct sequential analyses encouraged such critique.

The processes and techniques used for each data analysis procedure varied along with the nature and scope of the data collection activities (and the resulting yield in data types). Figure 4 displays an overview of the processes and techniques used throughout the study. It shows that both quantitative and qualitative data were collected. Further, it illustrates that analysis of the data was often conducted in cooperation with other individuals such as research assistants and critical friends. Some of the analysis techniques (e.g., case analysis meetings) naturally invited critical friends to help understand (or confirm how to interpret) what was happening. In other instances (wherever considered efficient and effective), the researcher engaged the assistance of one or more colleagues.

What	Who	How
<ul style="list-style-type: none"> <li>▪ Quantitative data were collected and used to identify general trends and themes</li> <li>▪ Qualitative data were collected and used to deepen understanding of trends and themes by examining specific, often more personal insights</li> </ul>	<p>Data analysis was conducted by the researcher, together (where appropriate) with:</p> <ul style="list-style-type: none"> <li>▪ Research assistants (n=8)</li> <li>▪ Developer group</li> <li>▪ Critical friends</li> </ul>	<p>Depending of the type of data collected, one or more of the following techniques were used:</p> <ul style="list-style-type: none"> <li>▪ Translation/transcription</li> <li>▪ Summarization of data</li> <li>▪ Calculation of mean, median, mode and standard deviation</li> <li>▪ Data coding and pattern coding</li> <li>▪ Interim documentation</li> <li>▪ Site visit reporting</li> <li>▪ Case analysis meetings</li> </ul>

Figure 4: Data analysis processes and techniques as applied in this study

To prepare for data analysis, data were translated (where necessary) and then transcribed into text files; and these files were then summarized into separate text files. Depending on the nature of the data, these summaries related to either quantifiable information (mean, median, mode and standard deviation) or qualitative codes (tags or labels for assigning units of meaning to descriptive or inferential information) and patterns (collections of codes identifying emergent themes, configurations or explanations). Please refer to Miles and Huberman (1994) for detailed descriptions of these techniques.

Data were analyzed both deductively (classified according existing schemes) and inductively (through recognition of emergent patterns). The (quantitative and qualitative) data summaries were chunked according to their relationship to the three criteria in the main research question. That is, they were first clustered by criteria (validity, practicality or impact potential) and then by sub-construct (for validity, those were: state-of-the-art knowledge and internal consistency; for practicality those were: instrumentality, congruence and cost; for impact potential those were: better quality materials and enhances professional development). Each summary contained a table with separate sections for content, support and interface issues. Within the tables, each item was color-coded for its relationship to various parts of the Cascade-Sea program or study. These summaries, as well as other interim documents and site visit reports helped to put the data collection activities into perspective. Further, they provided discussion tools for case analysis meetings that took place regularly among the developer group.

In addition to the data analysis techniques mentioned above, the researcher also used photographs, videotapes, developer logbooks and field notebooks during data analysis. Although the instruments described above provided the bulk of the data, revisiting these sources was extremely useful in reconstruction of events, and interpreting data in the proper context. Samples of these sources are shown in Figures 5 and 6. (Please refer to McKenney (2001) for more details.)



Figure 5: Photograph from first Tanzanian workshop

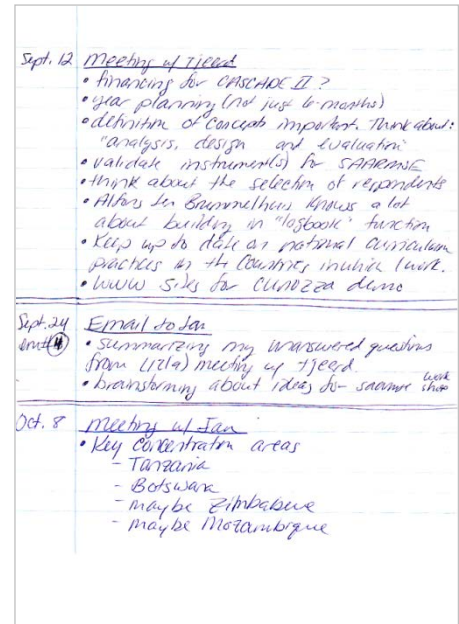


Figure 6: Page from developer log

#### 4. Yield of the project

Data collected throughout the CASCADE-SEA study were often analyzed twice: immediately after the data collection activities took place (to inform the following decisions), and at the end of the data collection period (to gain an overall perspective). This section discusses the findings, presented according to the three quality aspects investigated. In addition, it describes how these findings contributed to the evolution of the CASCADE-SEA program.

##### Validity

As described previously, validity pertains to state-of-the-art knowledge (about curriculum development, teacher professional development, computer-based support and how to realize it via the interface), and internal consistency (coherence throughout the various system components). Few participants disputed Cascade-Sea's possession of state-of-the-art knowledge; and similarly, sparse commentary was given concerning internal inconsistencies. In fact, numerous participants were enthusiastic about these aspects of the program. However, the degree to which the program may be labeled valid is much more difficult to pinpoint. For example, while participants generally agreed that Cascade-Sea contains state-of-the-art knowledge, some found the volume to be overwhelming, some were satisfied with it and still others considered it (present but) incomplete. Participant opinions also varied, though not as emphatically, in terms of the internal consistency of the program. Whereas most participants were satisfied with this aspect in relation to the interface and support, opinions diverged with respect to the content of the program. Some participants appreciated the inter-connectedness of the content in the various components, but the majority found this aspect to be (present yet) weak. Although determining where Cascade-Sea's validity should be placed on a quality continuum remains difficult, the participant reactions indicate that the support and interface are subject to less dispute than the content of the program.

### **Practicality**

Practicality refers to the way in which Cascade-Sea fits with contextual realities as well as the individual perceptions and/or beliefs of users in the target setting. This includes the notions of instrumentality (specifying procedures to complete a task); congruence (in this case, linking with the way teachers go about producing exemplary lesson materials in the target setting); and cost (the amount of investment effort compared to the return yielded). Generally speaking, the program was viewed to be practical, and based on the participant responses, 'quite practical' might be a better descriptor. Here too, the main area in which opinions diverged was in relation to the content.

With regard to instrumentality, participants generally appreciated the guidance offered by the program; although some concern was expressed (mostly by experts in curriculum development and teacher professional development) that Cascade-Sea could offer too much step-by-step guidance. To some user groups, the level of English used was seen to present an overly difficult challenge. Most participants felt that the program was quite congruent with the needs and wishes of the target group, and many emphasized the importance of using the program within a training setting. Opinions were more mixed with regard to the costs associated with using the program, in particular: time investment. Whereas some participants found Cascade-Sea to shorten the length of time they would otherwise invest, others found the opposite to be true, mostly because the program inspired them to be more thorough than otherwise would be the case. Although suggestions were given for improvements, participants were more consistently satisfied with the support and the interface aspects of the program. And even though their reactions were not always unanimous concerning the degree to which Cascade-Sea may be labeled practical, the overall consensus was far less varied when compared to validity aspects.

### **Impact potential**

In the case of Cascade-Sea, positively impacting the performance of its users means that it helps to create better quality materials than those that would be made without the support of the computer. In addition, the program should contribute to the professional development of its users. The data collected throughout this study indicate that Cascade-Sea does, indeed, possess the potential to positively impact the performance of its users, but that the extent of this potential is strongly influenced by how the system is used and by personal characteristics of those using it.

The structured nature of the program was judged by participants as useful in helping them articulate procedural specifications for the teachers who eventually use the materials. The support and layout of the materials created with the aid of Cascade-Sea were judged to be easy to use and comparable to or better than those created without the aid of the program. Further, participants generally indicated that they felt they learned from the Cascade-Sea experience, although some (mostly experts as well as a few user groups) raised concerns that the program could make things 'too easy' for the user and either stifle creativity or encourage 'laziness' as a result. Most participants noted that such concerns (as well as the potential benefits) would be influenced by contextual factors affecting implementation.

#### *How findings contributed to fundamental understandings and program development*

Because individual influences of research findings on Cascade-Sea's design would be too numerous to mention, this section contains three tables to *illustrate* how the research activities contributed to achieving the desired quality characteristics. They are comprised of carefully selected examples from each phase and cycle of activity, related to all three quality aspects (validity, practicality and impact potential) and all three program characteristics (content, support



and interface). Associated with each attribute introduced in Tables 3-5, a vignette is given that recounts design or revision decisions made, based on participant input. The numbers shown in parentheses correspond to the cells in Table 5.1 of McKenney (2001), which contains the original account of the empirical findings. Though it is not expected that most readers will reference the source table, we offer it here to (a) allow the interested minority to access the empirical reports; and (b) demonstrate transparency in how empirical findings feed design. Each of the tables relates to one of the main criteria sought: validity, practicality and impact potential.

Table 3: Examples of (re)design decisions based on findings related to validity (adapted from McKenney, 2001)

		<b>Validity</b>	
		<b>State of the art knowledge</b>	<b>Internally consistent</b>
<b>Content</b>		<i>Curriculum design and development knowledge; related professional development knowledge</i>	<i>Ideas in various components are in line with those in other areas</i>
		Participants evaluating the first prototype (13) recommended the use of concept mapping to help users organize their thoughts on lesson content. This suggestion led to an agreement with the producers of Mindman© to distribute their program with cascade-sea; and to the inclusion of sample concept maps for each topic covered within the program.	During early stages of gathering design ideas (3) and through later versions of product development (17, 19) participants emphasized that the link between the components (and related consequences) not only needed to exist, but should be transparent to users. Toward illustrating how rationale ideas relate to other parts of the program, Kasey's third button ("Tell me the link with my rationale?") was designed to speak to this need.
<b>Support</b>		<i>Advice on materials design; Guidance on embedding materials in professional development</i>	<i>Tips, guidelines, templates, advice and help functions are perpetually offered in a consistent fashion</i>
		Participants evaluating both the first and the second prototypes (13, 14) offered suggestions on how to help users improve the quality of their lessons. Such ideas shaped both the overt support offered (e.g., choice menus) in the lesson builder as well as the implicit support given through the structure of the lesson template (summary, preparation, lesson body, conclusion, teacher notes).	Participants recommended (17) that each main phase in the program produce some kind of tangible output that records user decisions, reflects them in another form and offers opportunity for changes, updates or tailoring. Each main component in cascade-sea now features such documents (rationale profile, analysis plan, lesson plans and evaluation plan) as well as guidelines on how and why to customize them.
<b>Interface</b>		<i>Maximizes the potential of modern ICT facilities</i>	<i>Functions as intended, regularly</i>
		Participants involved in evaluation of prototype two (14) suggested that the database connection be used in other areas of the program, not just for the lesson body. This prompted a complete revision of the 'Idea Book' and the 'Clip Art Gallery' such that they were integrated in a broader database that also contained vocabulary words (and editable definitions) and complete lesson plans. Further, this database was made accessible from the toolbox as well as the design area of the program.	Participants evaluating the third prototype (19) expressed frustrations with data loss. In some cases, this was due to power failures, and in other instances this was because users did not save their work. To relieve the user of this responsibility, an auto-save feature was built into cascade-sea, so that the program automatically records new work in the program every 10 minutes, without any action on behalf of the user.

Table 4: Examples of (re)design decisions based on findings related to practicality

Practicality			
	Instrumentality	Congruence	Cost
Content	<i>Guides the user step-by-step in making materials; Offers freedom to work at own pace and in own style</i>	<i>Links up with the needs, wishes and context of the users</i>	<i>Content should include enough of what users need, and not bog them down with unnecessary steps</i>
	Participants suggested (22) that cascade-sea allow the user to indicate when more (and less) support is needed by offering "I don't know" as possible responses to rationale questions. These options were built in, with the related consequence that cascade-sea makes suggestions for what to do next (in analysis) based on user uncertainties. But these tips remain optional.	Participants emphasized early on (9) and during design activities (26, 27) the importance of incorporating local resources into lesson materials. The 'Idea Book' started out as a way to spur on user thinking in this area, and evolved into database contents such as improvisation of equipment and activities that rely on cheap and or local supplies.	Participants recommended (13, 30) that the user maintain the majority of control over what to do and how to do it. Rather than forcing any particular path, regular suggestions from cascade-sea were preferred. (Re)design decisions based on this idea included the simplification of advice given to the user and its presentation (e.g., ✓, ✓+ as described in Chapter 4).
Support	<i>Explains how to use program clearly and concisely</i>	<i>Support is relevant and usable</i>	<i>Support should be extensive, lowering the threshold of investment cost to the user</i>
	Some participants found the level of English used in the program to be challenging (24). One response to this finding was the creation of Kasey's second button, which offers clarification of difficult words in each area of the program.	During the analysis phase, participants identified (9) the most promising setting for the use of the proposed program: trcs. Throughout design and development, attention has been given to maximizing the potential of a shared resource (e.g. by asynchronous sharing through the database and targeting small teams of designers, not individuals).	Participants especially appreciated the pre-made, editable samples that came along with cascade-sea (30) and requested much more of the same type of support. As a result, 'canned' documents were incorporated into each main area of the program (along with recommendations on how to customize them).
Interface	<i>Buttons, navigation and functions are clear</i>	<i>Interface 'feels' nice and safe, users are not alienated but motivated to use the program; Operates on technology that is available in the target setting</i>	<i>Interface should reflect the flexibility of the system, in which users determine how they would like to go through the program</i>
	Participants criticized (17, 22, 25) the navigation options (particularly the main panel) in various prototypes. This was revised three times before feedback on the final version confirmed that this aspect was quite clear.	Toward making the program 'feel' more inviting, participants recommended the use of more colors and icons (26). These ideas helped shape the current interface design.	Participants appreciated the ease with which they could alter documents (31). To clarify and emphasize this feature and the program's flexibility (e.g., building lesson inside program with guidance or working independently with the template) additional instructions were added.

Table 5: Examples of (re)design decisions based on findings related to impact potential

		Impact potential	
		Yields better quality materials	Enhances the professional development of users
Content		<i>The materials that are developed through use of cascade-sea should be valid, practical and effective</i>	<i>Cascade-sea should help users to think about materials development in a (more) systematic and thorough fashion</i>
		Participants suggested (22, 31) that exhaustive use of examples would help users to understand and thereby improve their work. This suggestion was taken and many examples, samples and templates were incorporated into the program. Comments given (55) show that users found these elements valuable, as seen through their explanation of why materials made with cascade-sea are of better quality than those made without the aid of the computer.	Participants offered suggestions (13, 15) pertaining to how cascade-sea might be able to help users generate a clear vision on what they want to do (in terms of making materials) and why. These ideas were incorporated into the rationale component (e.g., by asking users to consider the difficulty level of the subject matter addressed as well as the target teacher's experience, and offering tips accordingly). Participant comments (39, 40) show that these attributes were appreciated and that the process of creating a rationale profile is a valuable learning experience.
Support		<i>The materials that are created with cascade-sea should contain clear, useful procedural specifications</i>	<i>Teaches users where resources can be found (inside the program), and how they may be used and/or adapted for own setting</i>
		Suggestions were given as to how cascade-sea can help the user build up a well-structured lesson plan, including step-by-step guidelines. For example, ideas were given (32) as to how cascade-sea could remind the user (of the program) to remind the teacher (using the materials made with this program) to consider ways in which that lesson relates to everyday life. These (and similar) ideas were embedded in the system, and are cited by participants (36, 37) as contributing to more clearly structured lesson plans.	Early on, participants emphasized the importance of offering subject-specific support (2). In order to provide tailor-made support without the associated risks of rigidity, the cascade-sea program offers generic guidelines, illustrated through subject-specific examples (e.g., sample lesson series goals, concept map templates). Participants found this balance to be a useful start, although the addition of even more (subject-specific) examples was encouraged (56, 58).
Interface		<i>The materials that are generated with cascade-sea should evidence attention given to form and style</i>	<i>Interface helps (teams of) users to visualize the process of materials development and make their work more transparent</i>
		Participants gave suggestions on how to improve different aspects of the layout of the materials generated with cascade-sea (13, 15) such as, a separate area for 'Teacher Notes' (14). These ideas were implemented in the system, and were valued by participants who later commented (54) on the visual clarity of the materials. It was further observed that, even when encouraged to make any desired changes, most participants maintained the general form and style as generated by cascade-sea.	Participants suggested that cascade-sea can contribute to user thinking by both explicit prompts (such as posing salient questions [13]) and implicit structuring of tasks (as seen through the procedural and conceptual map offered in the main menu page [3]). These types of cues were appreciated by participants (38) who said that the structure helped their work to be more systematic, and that the program reminded teachers of responsibilities which might not ordinarily be considered.

The examples of (re)design decisions presented on the previous three pages offer insight into the way(s) in which the research findings contributed to the development of the Cascade-Sea program, and the evolution of the underlying design ideas.

### Design guidelines

Walker (1990) recommends that shared basis, or 'platform' of ideas' for curriculum development can be extremely useful in helping developers to make the thousands of necessary decisions as they shape their design. The design and development of the Cascade-Sea program was also structured by such a platform, containing ideas of varying degrees of abstraction. As previously mentioned, *foundational tenets* were formulated in accordance with the overall aims of this study; toward creating the Cascade-Sea tool, the implications (of these tenets) for design were examined. Further, theories and models for curriculum development in general and the creation of exemplary lesson materials in particular were studied to generate *development guidelines* for creating the program. Finally, by reflecting on the foundational tenets and the development guidelines, together, *product specifications* for the actual Cascade-Sea tool were elicited.

Each of these layers is described in McKenney (2001) and full presentation is beyond the scope of this chapter. Here, we present a sample from the layer of abstraction that lends itself most to use by other designer/developers: design guidelines. Table 6 summarizes key considerations concerning characteristics of exemplary lesson materials (what Cascade-Sea should help users to create).

Table 6: Content guidelines for the development of materials in the cascade-sea tool

Guideline	Implications
The users of the material should be able to, at-a-glance, ascertain what the proposed lesson is about in order to decide whether or not it is appropriate for their own use.	Cascade-sea should help the user to create a lesson summary that is both terse and easy to find. Connections to familiar resources, such as textbooks, should be included in such a summary.
A pre-requisite to a smoothly run lesson (especially in the case of new or innovative practices) is having the necessary materials and equipment on hand at the start of class.	Cascade-sea should (together with the user), generate a list of ways to prepare for the lesson (e.g., pre-mixing of solutions, background information, etc.). As much as possible, Cascade-sea should help the user to create any such supplementary materials (handouts, worksheets, etc.) by offering tools and resources to do so.
When faced with pressure to squeeze large amounts of content into already packed syllabi, teachers can use recommendations regarding how much time to spend on what kinds of activities.	In addition to realistically planning the time allotments throughout a lesson series, Cascade-sea should encourage materials developers to consider timing for each part of the lesson as well as suggestions on ways to efficiently and effectively conclude a lesson.
Both the system itself and the materials generated with the aid of Cascade-sea should contain reservoirs of what Ben-Peretz (1975) terms, 'curriculum potential.'	Cascade-sea should offer materials developers a wide variety of activity ideas (e.g., demonstrations, homework assignments, experiments, group projects, field trips, forms of assessment, etc.) which may be incorporated into the materials and serve as sources of inspiration for the end users.

Table 6: Content guidelines for the development of materials in the cascade-sea tool  
(continued)

Guideline	Implications
Creators of curriculum (be it materials developers or classroom teachers) are more likely to incorporate outside ideas when they can easily be adapted for one's own context or situation.	Cascade-sea should offer materials components in dynamic, rather than static formats. The program should also encourage its users to do the same. For example, text descriptions of activities should be editable so that the materials developers may tailor them if desired. Also, alternatives, substitutions and improvisations for materials (such as laboratory equipment and supplies) which might be difficult to obtain should also be recommended in the teacher guides.
Where applicable, content-specific theories of learning in science and mathematics (as opposed to general theories that are applicable across domains) should be incorporated into the materials.	Cascade-sea should assist the user in articulating specific expectations (problematic areas related to that topic, typical misconceptions regarding the content, likely student questions/reactions) so as to better prepare the end user of the materials and thereby lower any potential threat associated with trying out new or innovative activities.
The design of a message can influence the way it is interpreted and used.	Cascade-sea should encourage materials designers to consider the visual form and style of the teacher guides they create. Further, they should strive for a layout that accommodates the way teachers generally use such lesson materials (laid open on the teacher's desk for reference during a lesson).
The materials creation process is often best served by multiple perspectives toward development.	Cascade-sea should provide support and resources for further elaboration and improvement of the materials generated, including development activities that may be carried out without the computer.

### Process guidelines

The five tenets that molded the foundation of this research also form a useful framework for addressing additional questions concerning ICT-related design research, particularly in developing countries. So, in light of the findings from this study, the foundational tenets are revisited, once more. Based on these ideas, recommendations for continued and related research and development efforts concerning educational applications of ICT in developing countries are given (see Table 7).

Table 7: Considerations for research and development activities pertaining to ICT applications in developing countries.

	What to consider	Deliberation tips
Local relevance	Examine the target setting, together with the target group, to determine if the proposed innovation really addresses an expressed need in a culturally and contextually relevant fashion. Consider alternate versions of the innovation that address potential (long or short term) problems.	To succeed, innovations usually require the time and energy of the participants. Look carefully at what those people do (or, often more important, what they do <i>not</i> do) and why. Use this information to help capitalize on participants' intrinsic motivation to invest in the innovation.
Collaboration	Few, if any participants in innovation, are experts on all types of educational developments. Especially in new and inventive areas involving ICT, people tend to have less experience and therefore may have difficulty in contributing to certain dialogues. Expend effort to determine ways in which all participants can provide input in a fruitful and appropriate fashion.	Rather than overwhelming participants with wonderful sounding techno-possibilities, engage people in tasks that relate to those aspects of the innovation with which they are <i>already familiar</i> , and pay attention to what they indicate to be areas of concern, strengths or challenges.
Authenticity	All over the world (not only in developing countries), educational change is considered difficult, if not impossible to steer. At most, authorities may hope to shepherd developments in a particular direction. To do so, educational innovations must illustrate how they relate to what is already known and understood. The more genuine the test situation, the more genuine the results will be. It pays off to invest time and energy in seeking out naturally-occurring test-beds for product design, development, evaluation and revision.	Study what (if anything) has fostered successful change in the past. Determine how this innovation will connect with existing frameworks and the target population's own motivation, own facilities, own needs, as well as other on-going developments. This requires creative approaches to collecting useful information while maintaining the focus on the better interests of all parties involved.
Mutual benefit	Consider the main goals of the innovation and then look for micro-settings in which these things are already taking place (usually in a less explicit fashion). Capitalize on existing efforts toward both gaining additional support for the innovation and improving its overall quality and impact. The reality in developing countries is that most schools are poorly resourced and most teachers are un(der) qualified. If the innovation relies on more educated personnel or better facilities, take it to a logical 'home' where this may be found.	In the use of ICT in education, TRCs (teacher resource centers) and community centers are generally better equipped than schools. This pertains to physical infrastructure as well as the facilitator staff that provide support. In terms of the broader perspective, such centers (have the potential to) contribute to the overall growth of the community and may serve various sectors (education, health, business etc.) simultaneously.
Continuous (re)analysis	ICT is a field subject to rapid and unpredictable change. Particularly where resources are scarce (in developing countries), it is prudent to carefully examine how innovations may be structured for the long term. Take into account the current realities that are part of the 'bigger picture,' (e.g., availability of telephone lines or electricity).	Study the interplay between the <i>state-of-the-art</i> worldwide and the <i>state of practice</i> in the target setting. Consider the innovation in its ideal form, but (as much as possible) work toward that goal within the limits of current infrastructure and readiness-levels.

## 5. Reflection

### About the research focus

Anzalone (1991) predicted an increased recognition for the importance of sound instructional design in the creation of curriculum materials in developing countries; he further stated that the development of related capacities would undoubtedly be aided by computers. A step in this direction, the Cascade-Sea study has illustrated that the computer does have the potential to support curriculum development and teacher professional development in southern Africa. It has also highlighted the determining role of the context in which it will be used toward realizing that potential. Input from expert and user groups has indicated that this program (and/or a tailored version hereof) may be particularly useful to professional curriculum developers and preservice teachers, in addition to the target user group: facilitator teachers working at TRCs.

### About the research process

Educational design research was found to be particularly suitable for the problem that was central to this study. Several contextual factors increased the inherent challenge of designing support for curriculum materials developers, and the limited theoretical and empirical base from which to draw upon rendered it a more daunting endeavor. The design research approach was flexible enough to evolve alongside insights from each cycle, while maintaining focus on the long term goal of the intervention and of producing knowledge that could be valuable to a wider audience than participating designers alone. Besides the fact that there were direct benefits of this approach in terms of improved capacities on the ground, the approach afforded both opportunities, and challenges.

As stated previously, a design research approach was used to gain insight into desirable program characteristics, implementation strategies and the forms of support that would be desirable while also feasible. This design study evidences the characteristics of design research, organized below according to the set offered by Reinking and Bradley (2008):

- *Intervention-centered*: Having a positive impact on (resource) teacher-designers is central to the initiative.
- *Theoretical*: The program development was informed by research findings and theoretical works; it contributes to theory building about supporting curriculum developers in developing countries.
- *Goal-oriented*: This study explores how to support the complex tasks and professional development of (resource) teacher-designers in southern Africa.
- *Adaptive and iterative*: The tool and understandings about feasible implementation scenarios evolved in light of the experiences and research findings.
- *Transformative*: The intervention stimulates new practices in TRCs.
- *Methodologically inclusive and flexible*: Across the cycles, qualitative and quantitative data were collected; data source decisions were influenced by contextual opportunities and constraints.
- *Pragmatic*: Research, development and implementation efforts were driven by the desire to achieve a valid, practical intervention with the potential to have genuine impact on both the quality of materials developed and teacher-designer learning.

This chapter speaks to the need for more examples of useful long-term design research in the field of education in general and (technology-based) support for curriculum developers in particular.

Based on the experience from this and other studies, we remain optimistic about the potential of design research to contribute to scientific understanding through robust research while also informing the development of interventions on the ground. This approach is useful in a range of contexts, where solutions are needed to complex problems.

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## Exploring the Links between Dialogic Interaction and Written Argumentation in A level History (16-19 years old): A Design-based PhD Research Study

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Credits



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# 27. Exploring the links between dialogic interaction and written argumentation in A level history (16-19 years old): A design-based PhD research study

Diana Hilliard

## Abstract

*This chapter reports aspects of a design-based research (DBR) study conducted by a PhD researcher into a challenging and complex issue. History students aged between 16-19 years old within the UK educational system are expected to write arguments in their essays that include different perspectives and multiple factors. Research has been carried out in other academic disciplines to improve students' written argument skills (Andrews et al, 2006) by focusing on either the structure (Bereiter & Scardamalia, 1982; von Aufschnaiter et al 2008) or the process (Kuhn, Shaw, & Felton, 1997; Reznitskaya et al, 2001). Most History education research on argumentation recognises the links between arguing and thinking, but the most recent research has concentrated on the structural elements of written argument (Black, 2011; Chapman, 2006; Coffin, 2006 a and b, 2009). My research, however, focuses on the process and in particular on the links between spoken and written argument.*

*Following the dialogic approach (Wegerif, 2010, 2012), with its emphasis on the connection between argumentation, reasoning and dialogue, I conducted research into the links between dialogic interaction and written argument. Working with five secondary schools, I adapted and developed an intervention designed by Felton and Herko (2004) to act as a vehicle to instantiate dialogic interaction. In this way I was able to explore the role of dialogic interaction and its effects on the written responses of History A level students. Although only a small-scale study, the results suggest that the students who are able to engage in dialogic interaction before writing 'causation' essays appear to make the most improvement in their written argument. However, when students write History essays which involve documentary source analysis this improvement is not seen.*

## 1. Chapter overview

The intention of this chapter is to demonstrate how DBR can be an effective research approach for a PhD researcher. The chapter will be in six sections, comprising: an introduction to the problem and my research questions; a brief overview of my research, explaining the iterative process; a more focused discussion of the development of my initial theoretical framework, based in my literature review; a discussion on the adaptation of Felton and Herko's (2004) intervention, which became a central feature of my design artefact and the vehicle for the instantiation of dialogic interaction; followed by a short discussion on the yield of my project which might lead to further research. The chapter will conclude with my reflections on the process as a whole, which may be of interest to fellow PhD researchers.

## 2. Introduction to the problem

It is commonly accepted that students find it difficult to write effective argument in their essays and my experience working as a classroom teacher of A level History and Politics certainly supported this perception. (Within the UK educational system, A levels are exams – geared towards university entry – taken at the end of the sixth form (Years 12 and 13), when students have completed two years of advanced study and are usually aged 18/19). I emphasised that in A level History, in particular, the essay should be in the form of an argument. I ensured classroom discussion occurred before the students attempted their essay. The ‘talk’ generated was an important facet of my practice. My students were expected to think for themselves and to demonstrate that they did so by engaging in lively discussion.

Indeed, in my experience, I found that students wrote more convincing arguments if they had been encouraged to explore their ideas first. I was also aware that what we discussed was not directly translated into the essay: there was a further transition as the student made the learning his/her own. This led me to think that there must be some further, possible internal, reflection that occurred between our talk and the writing of the essay.

I became curious about the nature of our talk. I wanted to know what it was about the ‘talk’ that helped my students understand and express their arguments more effectively. I also wanted to understand the role of reflection in the process, especially the reflection that happened between the talk and the writing of the essay. The students’ arguments and interpretations – not mine – were discussed in the essays and I wanted to find out more about these two processes.

### Context of the problem

I realise that argumentation (that is all the processes – whether they be cognitive or structural – involved in engaging in and conducting a spoken and/or written argument) has been studied extensively in a range of subjects. English (Andrews, Torgerson, Low, McGuinn, & Robinson, 2006; Fisher, Jones, Larkin, & Myhill, 2010), and Science (Erduran, Simon, & Osbornel, 2004; Osborne, Erduran, & Simon, 2004; Simon, Erduran, & Osbornel, 2006; von Aufschnaiter, Erduran, Osborne, & Simon, 2008) are two such disciplines, but few studies have explicitly linked History and argumentation, particularly in the sixth form within the UK educational system.

Mitchell and Andrews (2001) highlight that the A level History essay is often written in such a way as to prevent argument being clearly expressed. The concentration on the ‘introduction, middle and conclusion’ format denies the opportunity to write a multi-factored response containing the necessary counterarguments fundamental to success at A level. However, tuition in History argument is not an explicit part of the syllabus despite argument’s fundamental importance to the discipline. There seems to be an underlying assumption that the critical thinking occasioned by analysing different forms of evidence is sufficient to ensure that students are able to produce effective written argument. My experience as a teacher of sixth formers for over 15 years suggested that this was often not the case. Mitchell and Andrews (2001) state that there is a discrepancy between the process and the product of the History argument. I would agree. It seemed to me that although students were surrounded by and even immersed in History argument, they were unable to translate this experience into written argument.

### **Using DBR as a research methodology**

Pragmatism was the underlying philosophical approach to my research problem. I was seeking a solution to a problem faced by many History students. Not only do they have to deal with issues associated with the structuring of an argument, they also have to appreciate and embrace the complex nature of History itself. They have to manage the tension between understanding History as an abstract concept and managing the practicalities of constructing an argument.

I wanted to investigate the links between spoken and written argumentation because I thought the solution to the problem that many students face lay in understanding the transition from one form of argument to the other - from the process to the product. I wanted to be able to determine whether the nature of 'the talk' might have a bearing on how easily that transition could be made and because my intention was to help all of my students, I wanted to determine who benefited most from 'the talk'.

Action research (AR) and DBR are both underpinned by the pragmatic approach. Both methodologies are geared to researching and resolving research 'problems' particularly in the classroom. DBR was used in this research study, however, because I was using and adapting a design artefact (a classroom intervention) in order to gain insights into and offer solutions to the research problem.

Anderson and Shattuck (2012) emphasise how DBR is a methodology that is geared to 'promote the effective transfer and translation of research into improved practice'. It is also a methodology that they state 'stresses the need for the development of theory which underpins the educational research' (pg. 16). Brown (1992) and Barab and Squire (2004) emphasise that the classroom, although 'problematic' with a 'multiplicity of variables that cannot be controlled' (Hoadley, 2004), is the proper context in which to conduct educational research. Hoadley (2004) goes further, to stress that 'theory enacted through a design intervention gains a unique strength'. My PhD study, however, only allowed me limited time in which to design and develop classroom interventions, so I adapted one derived from the literature review which had been devised by Felton and Herko (2004) and will be described later.

I decided to adapt Felton and Herko's intervention to allow me to do two things. Firstly I was aware that the argumentation involved intense interaction and I wanted to investigate how the interaction could be linked to written argument. Could the interaction be considered 'dialogic'? (Wegerif, 2012). Wegerif's interpretation of dialogic (2005, 2010, 2011, 2012) is based in Bakhtin (1981). In this way, dialogic means more than simply engaging in dialogue. 'Dialogic' talk is a type of talk that is exploratory in nature where the two 'addressees' do not engage in a discourse that is full of 'winning and losing', but instead orient themselves to the dialogue itself in an effort to explore ideas to reach a deeper understanding of the issues being discussed. The students do not argue to reach consensus - to 'beat' their opponents - but instead to explore their differences to appreciate other sides to the argument.

Secondly, I wanted to discover if Felton and Herko's (2004) intervention, designed to help American Humanities students move from one-to two-sided argument, could be adapted to meet the different needs of UK History students. A level History students need to be able to write a multi-factored response which is more than a two-sided argument.

### 3. Brief overview of the research process integrating research questions

My overarching aim was to help History students to write more effective argument in their A level essays. I was aware that the 'talk' generated between my students and I seemed to be instrumental in improving their written argument. I wanted to explore 'the talk' and investigate its links with written argument in order to design a classroom intervention rich in 'talk' that would help future History students write better essays. Figure 1 (found below) shows the research process.

My initial research question was 'What is it about the talk which helps students improve their written responses?' This first question was explored through an extensive literature review. Based on the literature review, I conjectured that ideas generated by argumentation rich in dialogic talk, as defined in the research of Wegerif (2005, 2011, 2012, 2013) and Wegerif and Mercer (1997), would be taken into the written argument of the students following the 'snowball hypothesis' of Anderson et al (2001), Reznitskaya et al (2001), Reznitskaya and Anderson (2006) and Reznitskaya et al (2007). Based on this initial theoretical framework - Design Framework 1 - I suggested that if I could engage my students in argumentative interactions rich in dialogic talk - "dialogic interactions" - I would be helping them to improve their written argument. To test this conjecture and following Wademan's (2005) GRDM model, I conducted fieldwork - the first iteration - to determine how History argument was taught in schools and whether 'dialogic interaction' was already an aspect of the instruction in History argumentation.

The fieldwork was in two stages: expert opinion and exploratory fieldwork. Expert opinion comprised semi-structured interviews conducted with History education researchers and email exchanges with A level History examiners; the exploratory fieldwork was conducted through semi-structured interviews and classroom observations. A level History teachers and students were interviewed in four secondary schools and classroom observations were conducted in History A level lessons in each school. The findings from the exploratory fieldwork demonstrated that dialogic interaction was not an aspect of the History argumentation instruction. The input from the History education researchers, combined with the findings of the exploratory study, led to the creation of the next theoretical framework, Design Framework 2. This was essentially an affirmation of my initial theoretical framework because my original conjecture - that ideas generated through argumentation rich in dialogic interaction could be taken into the written argument and in this way improve the essays of my A levels students - had neither been confirmed nor refuted. My fieldwork had produced little evidence of History argumentation taught in this way and the participants, both teachers and students, had indicated that my conjecture might be successful if tried.

Design Framework 2 was the theoretical basis for the design of the classroom intervention. The Felton and Herko (2004) intervention, derived from the literature review, focused on dialogue as the means to help students move from one-to two-sided argument. The emphasis on dialogue was what attracted me to the intervention. Although Felton and Herko (2004) were able to suggest that their students' essays improved through engaging in dialogue, I was not simply replicating their work. Felton and Herko (2004) did not analyse the student argumentation in the way that I wanted to and so I adapted their intervention in line with the findings of my exploratory fieldwork to allow me to explore dialogic interaction.

The newly adapted classroom intervention was then trialled by classroom practitioners - the teachers in one of the schools participating in the study - this was Iteration 2. I wanted to observe how classroom practitioners would use the intervention and how effectively it could be



incorporated into classroom practice. Each teacher taught a different A level subject, Law, Sociology and History, and focused on different aspects of the intervention. Although only aspects of the intervention were trialled, the results of the classroom observations and the teacher feedback suggested that students' written argument could improve. Teacher feedback acknowledged that when students were engaged in classroom interaction there appeared to be improvements in written argument.

The findings of the teacher trials had emphasised the inherent success of the intervention, but it had been difficult to determine whether dialogic interaction had been instantiated and it was impossible, therefore, to determine whether dialogic interaction had a role in the improvement of the students' essays. The findings of Iteration 2 were thus incorporated into Design Framework 3, which was the basis for the next iteration.

Case Study 1 was conducted to test the entire intervention as a vehicle for the instantiation of dialogic interaction. Classroom observations were made, essays were marked pre- and post-intervention and post-intervention semi-structured interviews were conducted. Student questionnaires were also completed to offer feedback on the immediate experience of the intervention and to suggest developments to the process. The results of Case Study 1 suggested that dialogic interaction was instantiated, but only in one of four interactive groups. Those students, however, who were able to engage in argumentation rich in dialogic interaction were the students whose essays improved the most. It was also seen, through examining the transcripts of this group, their essay plans and their essays, that one student's 'voice' was very clearly taken into the essays. This student appeared to undergo a leap in her learning during the interaction and it seemed to be pivotal in the learning of the other group members too. However, although every participant within the case study appeared to make an improvement in their written argument, not every group was able to engage in dialogic interaction.

It had become clear during the argumentative interactions of the intervention that the discourse of 'winning and losing' rather than exploring differences had been prevalent and may have prevented the instantiation of dialogic interaction in the other groups. Design Framework 4, therefore, emphasised persuasive argumentation to break through the 'winning and losing' discourse so that more students would be able to engage in dialogic interaction. The fourth iteration, which saw the testing of this conjecture, comprised two parallel case studies which focused on different aspects of History argument. Again, dialogic interaction was instantiated, but not for each group, though there was an overall improvement in written argument in Case Study 2 - just as there had been in Case Study 1. In Case Study 3, however, this pattern was not present. It was observed that those students who had to integrate documentary source analysis in their written argument found it difficult to engage in effective oral argumentation. This also seemed to be reflected in their written argument. The findings from case studies 2 and 3 were then taken to form Design Framework 5, the continuation of the project if further research was to be conducted in the future.

The following diagram gives a visual representation of the research process showing the frameworks and their related iterations.

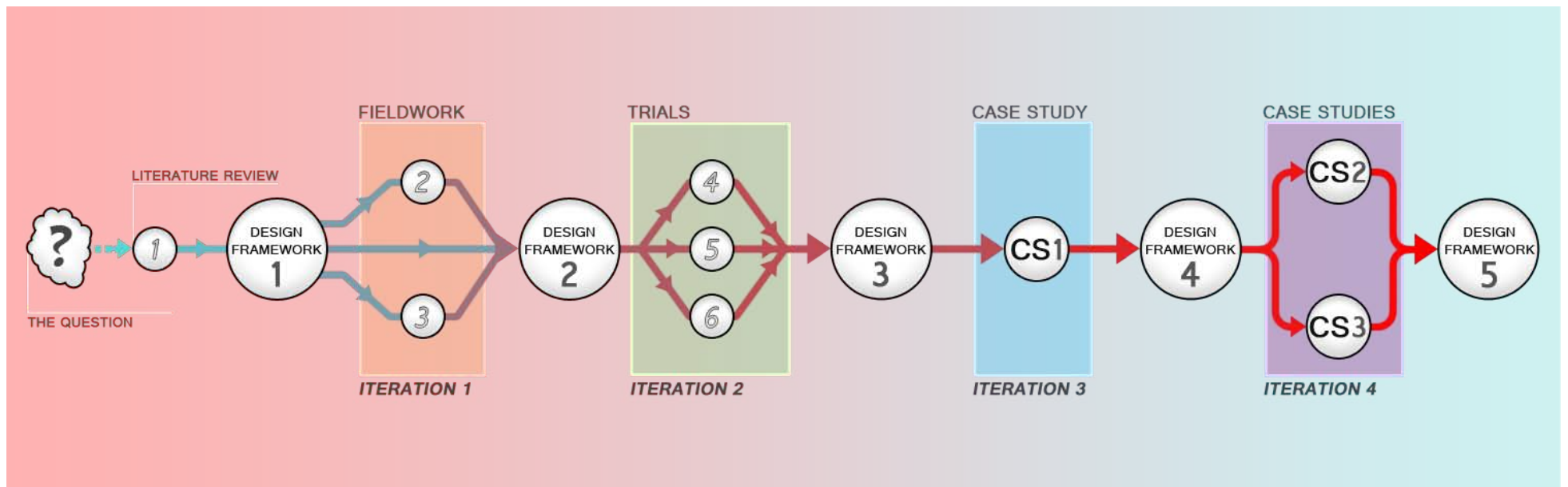


Figure 1: The research process, showing the design frameworks and their corresponding iterations (taken from Hilliard, 2013, p 28)

**Note:** 1 = Literature Review, 2 = Expert Opinion, 3 = Exploratory Fieldwork, 4 = A2 Law, 5 = AS Sociology, 6 = AS History, CS = case study.

The diagram shows the research process – ‘the mini-cycles of research’ – and demonstrates how each design framework is implemented and developed.

## 4. Development of Design Framework 1

In this section I will focus on just one aspect of my research process – the development of the initial theoretical framework derived from the literature review.

### **Review of literature**

What is presented here is only part of an extensive literature review. The literature, which formed the basis for the theoretical underpinning of Design Framework 1 included literature on the following three areas, some of which is discussed here: firstly, History argumentation; secondly, links between arguing and thinking and dialogue in classroom interaction; and thirdly, links between spoken and written argument.

### ***History argumentation***

History education researchers tend to locate their interpretation of History argumentation as implicit within the study of History. Van Drie and van Boxtel (2008) demonstrate clearly that they feel that History argumentation, carried out in whole-class and group activities, is at the heart of History learning. However, they suggest that although central to History learning, argumentation is only a facet of History reasoning. They offer a framework for History reasoning which encompasses the three fundamental aspects of describing, comparing and explaining change. They further develop these aspects by considering the following six features of History learning: use of substantive and meta-concepts, asking historical questions, use of sources, contextualisation and finally argumentation. As educational psychologists, they follow the cognitive approach using case studies based in experimental methods to conduct their research. Invaluable as this approach is, their research does not allow me to access the actual processes involved in a History argumentation.

O'Reilly (1991) follows a different approach. His classroom practice is explicitly designed to improve the argument skills of his students by incorporating informal reasoning, in the form of critical thinking. He uses Toulmin's model (2003) of informal reasoning, which gives structure to the argumentation but, again, this does not appear to produce anything more than the superficial product of History argument. He indicates that his students could structure a History argument, but they are not thinking about the History at all. This can equally be said about Karras' study (1993). Implicit in the argumentation Karras generates is the same informal reasoning model that O'Reilly uses, although Karras goes out of his way not to consider it a 'critical thinking' model. Instead he suggests that it is a 'history thinking' model. Fordham (2007) also uses a similar critical thinking model, which serves as a framework for Black's research (2011, 2012).

Donovan and Bransford's work (2005), however, shows how History lessons can be developed to create the opportunity for deeper learning, where argumentation is implicit rather than explicit. Pontecorvo and Girardet (1993), concentrating as they do on discourse and shared reasoning, show clearly how the process of arguing develops the students' learning. Their approach is more dialogic because they emphasise how students improve when they are not teacher-led but teacher-guided and where the focus of the learning is on the collaborative discourse.

### ***Links between arguing and thinking and dialogue in classroom interaction***

The literature on discourse and reasoning, however, is not confined to History learning. Piagetian (1975) or Vygotskyian (1986) premises underpin most current educational literature, suggesting that conceptual conflict is a means of fostering cognitive development.

Fawcett and Garton's (2005) research examines both Piagetian and Vygotskian theories at the same time and find that they are not incompatible. By comparing children working collaboratively in dyads with children working as individuals on similar tasks, Fawcett and Garton (2005) demonstrate that those who work collaboratively in dyads are more successful. They suggest that children who are placed with others who hold opposing ideas, so that there was a source of conflict within the group, also benefit, but not significantly. What they are also able to demonstrate is that the children who are encouraged to talk in their groups to explain their reasons for their choices seem to benefit the most. The children who are less able benefit from having a significant other helping them in their Zone of Proximal Development (ZPD) (Vygotsky, 1986) and the more able children, providing they are expected to explain their reasoning fully, also improve. Collaboration produces significant results, but the difference in the talk generated in the small groups is possibly a more important finding.

Schwarz and Linchevski (2007), however, suggest that a simple discussion between students does not lead to conceptual change, even if they set up the dyad as a conflictual relationship, following Piaget's thesis. What does appear to lead to conceptual change is the opportunity to test a tangible contradiction. What also becomes clear is that the less able student in a mixed ability dyad benefits whether they are in the talk mode or not, whereas the most able student only benefits when (s)he is given the opportunity to discuss his/her reasoning fully. As Fawcett and Garton intimate in their research, it is the type of talk that matters. Fawcett and Garton (2005) and Schwarz and Linchevski (2007) also follow a cognitive approach and use children who are of primary school age as participants. Again, although they offer insight into collaborative talk they do not offer an explanation for argumentative talk, but do offer an appreciation of the role that conceptual conflict has in cognitive development.

Wegerif's 'dialogic talk' (2010 a and b, 2011, 2012,) develops the notion of 'talk' further. What seems to be fundamental to Wegerif's argument is not the dialogue itself but the conceptual space - a dialogic space - created by the dialogue, in which reflection and thinking occurs. It is a space embodied not just by those engaged in the dialogue, but by the recognition that the talk is happening in front of an audience - either a physical audience or an audience of an 'infinite Other'. Talk does not happen in a vacuum: it is either generated in response to or in anticipation of something else being said. Espousing Bakhtin's (1981) viewpoint, Wegerif (2012) talks about the 'calling forth of talk'. He suggests that 'talk' is a form of communication which is brokered anew but based on past and future occurrences, and as such meaning is not fixed but is continuously being negotiated. Hobson's work (2002), which focuses on how young children learn to talk, illustrates this phenomenon. Hobson suggests that communication is formed or mediated between others through an almost organic 'space'. It becomes essential, therefore, to acknowledge that the silence and interaction are as important as the dialogue - it is the calling forth to engage in a dialogic space that can lead to improved learning. The research of Fawcett and Garton (2005), Schwarz and Linchevski (2007) and Wegerif et al. (1999) was conducted in primary schools, and although it emphasises the importance of 'talk', there are no links with written outcomes.

### ***Links between spoken and written argument***

In 2006, Andrews, Togerson, Low, McGuinn and Robinson (2006) conducted the extensive Evidence for Policy and Practice Information for Co-ordinating Centre (EPPI-Centre) survey into argumentation for the 7-14 year age group into the ways in which written argument could be improved. Part of the survey highlighted the work of Reznitskaya et al (2001) and Anderson et al. (2001), which has similarities to the collaborative work of the research so far discussed.

Their 'snowball hypothesis' explains the way words and ideas are picked up and developed as they are 'bounced around' the classroom. Again, the basis of these studies is primary classroom practice, and viewed from a cognitive perspective. Felton, however, developed these ideas further (Kuhn, Shaw, & Felton, 1997; Felton & Kuhn, 2001; Felton, 2004). Working with Herko in 2004, he suggested that dialogue and the interactive aspects of working collaboratively and, in particular, in conducting an oral argument, would be an effective way of helping students write more convincing argument. This was particularly pertinent research because it was being conducted with secondary school Humanities students within the American educational system. An intervention was designed comprising classroom activities to test the hypothesis.

**Design Framework 1 - the initial design principles**

The literature has so far suggested that I needed to create opportunities for my students to engage in talk in dyads, and to hold conflicting opinions but to be open to change. Wegerif's (2012) work in dialogic talk emphasised the creation of a space for exploring difference without the necessity to arrive at a consensus. I do not want the sixth formers to argue for consensus, I want them to find their own voices to argue for themselves and explore the different perspectives and interpretations of History Wegerif's thesis also states that when children engage in dialogic talk they are open to new ideas and gain a more rounded appreciation of the subject matter in which they are operating. This is essentially what I wanted my students to achieve - I wanted them to be open to change and to explore different ideas. The following table shows the pedagogical principles for Design Framework 1.

*Table 1: Design Framework 1*

<b>Design Framework 1</b>
Students should engage in oral argumentation before they write arguments in their essays.
Students should engage in persuasive argumentation.
Students should be encouraged to make judgements about History which will become the basis of their arguments.
Students should follow ground rules to encourage them to engage in dialogic talk.
Students should be encouraged to reflect on their oral and written arguments.

(Taken from Hilliard, 2013, p. 68)

**5. Basis of the intervention : Felton and Herko's workshop intervention**

In this section I will discuss the basis of the intervention and how it was adapted to become the classroom intervention of the research study. In principle, I was underpinning my intervention in dialogic theory but I needed to be able to test the idea that 'the talk' was linked to an improvement in oral argumentation and ultimately in written argumentation.

Felton and Herko (2004) suggest that students engage in argumentative dialogue easily, though this is a contention with which others would not agree. Kuhn (2005, 2009), for example, suggests that although children seem to argue 'naturally', teenagers must be taught to argue, whereas Schommer-Aikins and Easter (2009) demonstrate that student perceptions of what constitutes an argument can impact on their ability to argue in either oral or written forms. Felton and Herko had designed their classroom intervention as a workshop of three 90-minute sessions and its aim was to help American Humanities students aged between 16 and 17 to move from writing one-to two-sided argument in their essays. The Humanities students had

been unable to include counterargument in their essays and often produced claims that were unsupported by evidence.

Felton and Herko (2004) based their research on earlier research by Kuhn, Shaw and Felton (1997) into dyadic interaction, Kuhn and Udell's research (2003) into improving argument skills and Reznitskaya et al's (2001) 'snowball hypothesis', which suggests that spoken argument can be picked up and translated into written argument. Felton and Herko designed their intervention to include, among other things, formal instruction on written argument. Central to their research however were the argumentative interactions between students in groups of four. Two students who held opposing views argued against each other while the other two observed silently, reflecting on the content of the argument as well as the progress of the argument. In this way they were being encouraged to engage in meta-strategic thinking on the nature of argumentation. The issues chosen for the argument were contentious - the death penalty - and designed to create intense interaction. Felton and Herko (2004) discovered that encouraging their students to engage in these interactions improved their students' written argument.

### **Adapting the intervention**

Although Felton and Herko's workshop intervention had proved to be successful in improving the written argument of American Humanities students, it was important that I did not simply replicate the work of Felton and Herko (2004) - their work needed to be developed to meet the needs of UK students. I used the findings from my exploratory fieldwork conducted in the History departments of four secondary schools to adapt the intervention further.

Unfortunately, there is no space in this chapter to present and discuss the findings from the exploratory fieldwork, which - as briefly mentioned in the research process - had looked at how History argument was taught in schools. During the semi-structured interviews conducted, I asked teachers and students to suggest ways in which they thought the teaching of History argument in schools could be improved. I also asked them what made learning History argument difficult. The responses to these questions were used to adapt the Felton and Herko (2004) design accordingly.

I felt the staged series of activities which was at the heart of Felton and Herko's intervention (2004) could be exploited not only to improve the written argumentation of my students, but also to allow me to explore the verbal interaction in which the students were engaged. I wanted to find out how and why this process occurred. I wanted to exploit the intervention so that the arguing process could be easily monitored and observed. I thought, too, that a subsequent stage could also be developed to allow me to study the introspective form of dialogic interaction. I wanted to clarify whose voice would be evident in the plan. I wanted to explore the impact that argumentation rich in dialogic interaction had on the students' written argument.

### **The adapted intervention**

The following table offers a visual representation of the classroom intervention, showing the intertwining of the underpinning theories, the findings of the exploratory fieldwork and the adaptations to Felton and Herko's (2004) intervention.

Table 2: The classroom intervention

Theory		Fieldwork findings from teachers and students from four schools	Intervention	
Design Framework 2 developed from Design Framework 1 through the findings of the exploratory fieldwork	Additional theory from literature review		Stage	Scheme of work Suggested activities
<p>Students should make their own ground rules to encourage them to engage in dialogic talk.</p> <p>Students need to understand how to engage in dialogic talk. Students should take part in collaborative activities designed to promote positive peer interaction. Students should be encouraged to engage in argumentation that is based in dialogic talk.</p>	<p>Argumentation needs clear guidelines to prevent harm (Schommer-Aikens &amp; Easter, 2009).</p>	<p>Teacher talk dominates whole-class work and students are passive consumers of information. Little evidence of peer interaction: very few paired or group discussions. Questioning focused on recall, not dialogic exploration. Interactions not dialogic. (Classroom observations)</p> <p>Students often lack confidence, so need to be encouraged to engage in the learning process. (Yr 13 responses in interviews)</p>	<p><b>1</b></p> <p><b>Setting the Ground Rules</b></p>	<p><i>Paired or group work – establishing group/class rules democratically.</i></p>
<p>Students should engage in persuasive argumentation. Students need to be aware of the different forms of argumentation. Students need to be taught to argue and counter-argue points.</p>	<p>Teenagers need to be taught to reason Kuhn (2009). The term ‘argument’ has several different interpretations and needs to be clarified (Coffin and O’Halloran, 2008). Persuasive argument leads to concept change and cognitive development (Mason, 2001).</p>	<p>Essay and argument often become synonymous – distinction needs to be made. Little evidence to demonstrate ‘persuasive argument’ is implicit in classroom argument. Discourse of winning and losing prevalent. Debates and paired presentations did not allow students to counter argue individual points Argumentation confined to winning and losing. (Classroom observations)</p>	<p><b>2</b></p> <p><b>Argument Instruction</b></p>	<p><i>Whole-class activity – watch YouTube clip.</i></p> <p><i>Whole-class discussion – what is a good History argument?</i></p> <p><i>Teacher-led PowerPoint presentation – forms of argument demonstrating links to History argument.</i></p> <p><i>Arguing practice in threes – two argue and one judges.</i></p> <p><i>Judges’ feedback leading to whole class discussion – revisit what makes a good argument.</i></p>

Table 2: The classroom intervention (continued)

Theory		Fieldwork findings from teachers and students from four schools	Intervention	
Design Framework 2 developed from Design Framework 1 through the findings of the exploratory fieldwork	Additional theory from literature review		Stage	Scheme of work Suggested activities
Students should be encouraged to make judgements about History which will become the basis of their arguments.	Students taking ownership of their own work (Claxton, 2001; Dweck, 2000).	<p>Often students do not know what they think and are passive bystanders in the teaching and learning process.</p> <p>Little evidence of students making judgements about History controversies or about source analysis.</p> <p>Teacher and/or textbook interpretation taken on face value. <i>(Classroom observations)</i></p> <p>Encouraging students to have the strength of their convictions – daring them to demonstrate what they think. <i>(Teacher interviews)</i></p>	<p><b>3</b></p> <p><b>Making a Judgement</b></p>	<p><i>Whole-class discussion – History essay title – setting an argument in place – brainstorm what title means.</i></p> <p><i>Individual decision making in silence.</i></p> <p><i>Physical whole-class participation – standing on a continuum.</i></p>
Students should take part in collaborative activities designed to promote positive peer interaction.		<p>Students do little ‘talking’ in the classroom – they answer questions, but do limited paired or group work. <i>(Classroom observations)</i></p> <p>Students want to work collaboratively and think it will help their learning. <i>(Yr 12 and Yr 13 interviews)</i></p>	<p><b>4</b></p> <p><b>Preparing for the Argument</b></p>	<p><i>Collaborative paired work – generating points in preparation for arguing in fours.</i></p> <p>Dyads compare their own points and develop others, supporting them with appropriate evidence.</p>



Table 2: The classroom intervention (continued)

Theory		Fieldwork findings from teachers and students from four schools	Intervention	
Design Framework 2 developed from Design Framework 1 through the findings of the exploratory fieldwork	Additional theory from literature review		Stage	Scheme of work Suggested activities
Students need to learn to argue and counter-argue points. Students should be encouraged to engage in argumentation that is based in dialogic talk. Students should be encouraged to reflect on their oral argumentation.	Felton and Herko (2004) argumentative interaction with meta-strategic reflection on process of argument.	Students either engage in whole-class debate or 'boxing ring' argument, but with an audience. Only one example of arguing in fours, but was isolated and did not contain reflection on the process of argument. <i>(Classroom observations)</i>	<b>5</b> <b>Arguing in Fours</b>	<i>Collaborative argumentation in fours</i> – structured argument to argue point-by-point and pair-by-pair with other dyads, reflecting on process and development of the argument.
Students should be encouraged to reflect on both their oral and written argumentation.	Making the monological world of the written word more dialogic – Bereiter and Scardamalia (1982).	Though they are advised to, students rarely plan their essays and start their work with no clear idea about what they are going to write or why. <i>(Classroom observations</i> <i>Yr 12 Student interviews)</i>	<b>6</b> <b>Planning the Response</b>	<i>Individual work</i> – writing plans.  <i>Individual work</i> – review other students' plans – comment on argument and content of essay.
Students should be encouraged to reflect on their written argument.			<b>7</b> <b>Writing the Essay</b>	<i>Individual work.</i>

(Taken from Hilliard, 2013, pp.142-144)

The research process has already been described, but sections of the above classroom intervention were adapted as the research process continued to meet the different research questions. For example, to effect more persuasive argumentation to counter the prevalence of the winning and losing discourse, one of the pedagogical principles of Design Framework 4, the focus of the small PowerPoint presentation and the role-play carried out in stage two of the intervention, were changed.

## **6. Yield of the project**

### **Design principles**

The adapted intervention was able to instantiate dialogic interaction so that I could explore the links between dialogic interaction and written argument. My research suggested that the students who were most actively engaged dialogically in the argumentation process were the ones whose written work improved the most. That this finding was not confined to the most able students is encouraging, because it means that more students can access important aspects of historical understanding and knowledge acquisition.

### **Involvement of practitioners**

A level History is a high-pressure undertaking for teachers and particularly for students, with the current emphasis on examinations. As an experienced History teacher as well as a PhD researcher, I was in a position to work with the teachers and students sometimes as both teacher and researcher. I was not, however, in a position to create opportunities for the professional development necessary to help the teachers appreciate the different emphasis on argumentation and dialogic engagement in the classroom. I knew that I needed to be able to produce more evidence before I could expect the teachers to change their practice; the research was thus conducted with considerable teacher input, but the collaboration between researcher and teacher was not an equal. Erduran et al. (2004) have demonstrated that it takes at least two years of continuing professional development and researcher support before teachers can be expected to change their practice. Under the pressured PhD format, I was unable to offer such support. Besides, I knew that if I wanted to convince teachers that the intervention would be an effective way of improving students' written argumentation I needed to prove it first.

### **Potential generalisability**

This was a small-scale study and several key aspects of the research were based in interpretative practice, which means that it would be difficult to state that there could be explicit replication of my experiences in all A level History classes. Wang and Hannifin (2005) suggest that in attempting to validate the 'generalisability of the design', DBR researchers balance the design principle and theory development with local effectiveness. The intervention appeared to be a success on the three occasions I conducted it. Each time it was with a different group of students, in a different school, and the focus was on a different element of History learning. In that respect, it might be that the intervention itself is replicable while other aspects may not. Dialogic interaction was instantiated in each of the trials, but not for every student dyad and it would be necessary to conduct different trials to determine whether the argumentative process actually detracts from dialogic interaction and whether a more collaborative stance might occasion more instances of dialogic interaction in the classroom.

## **7. Reflection: lessons learned**

The purpose of this chapter was to demonstrate how a PhD researcher used DBR as a means of conducting an investigation into a complex educational problem. It was only possible to follow an adapted DBR approach because of the time limits attached to doctorates pursued in the UK. This means that there was less scope for testing alternative methods to resolve the problem of students' difficulties in written argumentation. The utilisation of a previously constructed intervention allowed me to conduct iterative cycles of development and assessment to attempt to understand and resolve the research problem. This was a small-scale study and for a more thorough testing of the intervention, more extensive trials should be carried out.

It has been a rewarding experience, and at times challenging. Trying to juggle the demands of a PhD programme with the structure of a pressurised A level History course was potentially difficult. However, the fact that there was more than one school involved alleviated some of the problems and added a richness to the research process that would otherwise have been missing.

The following diagram, which was designed after Herrington, McKenney, Reeves and Oliver (2007), shows the tasks and processes involved in conducting research to meet the requirements of the adapted DBR methodology. The key highlights the iterative and collaborative nature of the research. It also emphasises another important component of DBR: the dissemination process. It is set within the framework of a three-year PhD programme.

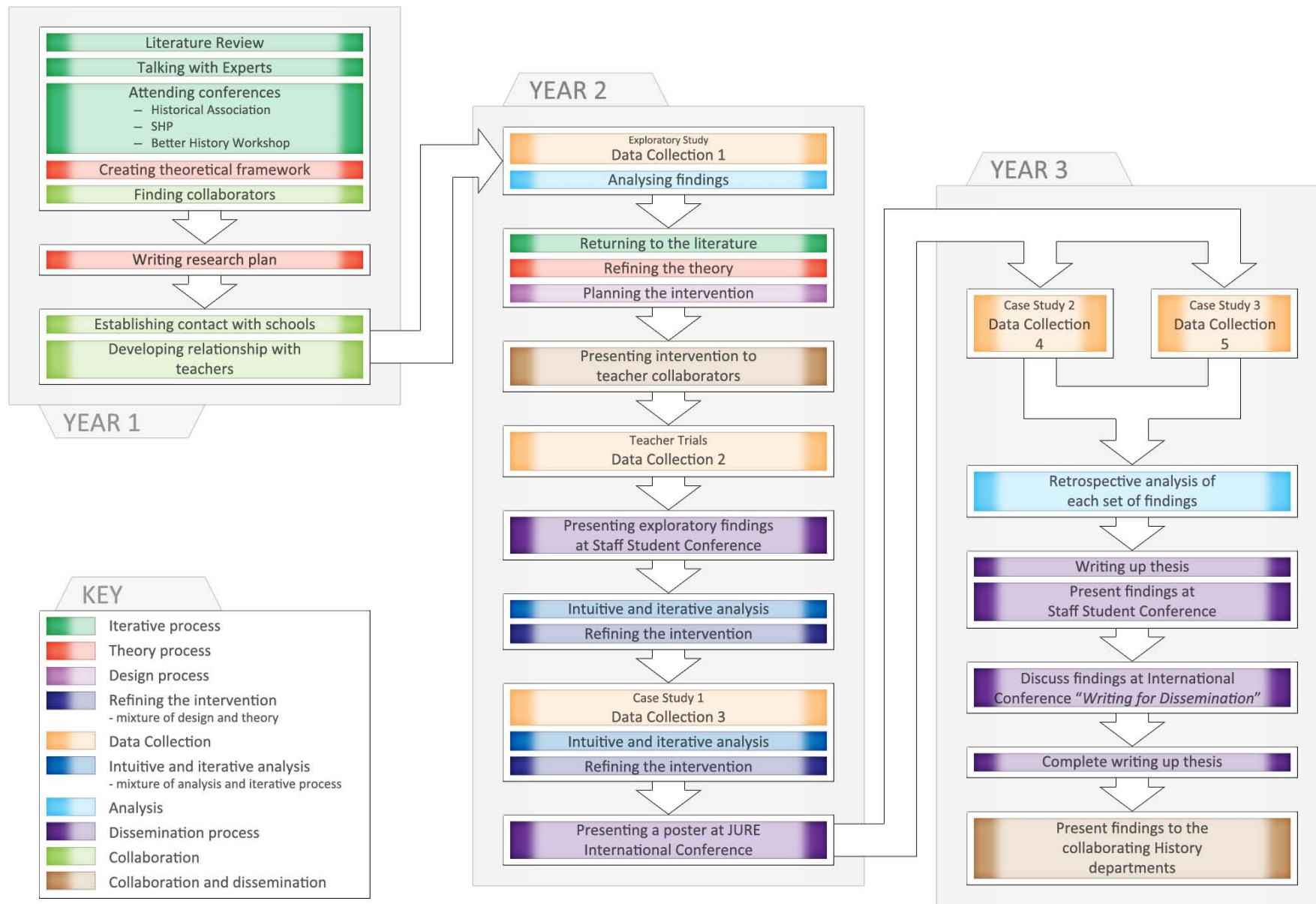


Figure 2: Research activities within a three-year PhD study (taken from Hilliard, 2013, p 82)

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## Design and Evaluation of Micro-Scale Chemistry Experimentation in Tanzanian schools

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# 28. Design and evaluation of micro-scale chemistry experimentation in Tanzanian schools

Fidelice Mafumiko, Joke Voogt & Jan van den Akker

## Abstract

*Macro-scale chemistry (also referred to as small-scale chemistry) is a teaching methodology wherein practical (laboratory) chemistry teaching is conducted to students while utilizing very small quantities of chemical substances and correspondingly small (often simple) apparatus. The method enables a school to reduce significantly the cost of chemicals, the cost of waste disposal and the dangers associated with manipulation of chemicals. This chapter reports on the Micro-Scale Chemistry Experimentation (MSCE) study that was set out to explore, design and evaluate a small-scale and low-cost teaching approach that could contribute to improved implementation of practical chemistry teaching in secondary schools in Tanzania. In view of constraints of resources, infrastructure, time and overloaded syllabuses, the study was designed to introduce micro-scale chemistry learning activities as a means to perform practical work in A-level chemistry classes without the need for well-equipped laboratories. Such activities also aimed at providing opportunities for students to engage in a process of active learning away from the usual 'passive roles' of note taking, listening and watching. The overall design of the study comprised of various stages: first, a front-end analysis, comprising of context analysis and literature review; afterwards, the cyclic design and formative evaluation of prototypes of micro-scale chemistry based exemplary lesson materials. The formative evaluation (carried out via expert appraisals and classroom try-outs) aimed at increasing the quality of prototypes. The last stage of the study (summative evaluation) involved field-testing of the MSCE approach via refined (final version) micro-scale chemistry design based lesson materials as part of summative evaluation. This stage focused on the effectiveness of the MSCE approach as measured through teachers' opinions about the approach, actual use of the approach in the classroom, students' experiences and learning outcomes. Overall, findings of the formative and summative evaluation showed that the MSCE approach is not only easy to use but also makes chemistry lessons more interactive, interesting and enjoyable, allowing students to carry out experiments by themselves, collaborate with peers, and communicate with their teachers freely. Besides, the findings indicated that students develop better analytical skills by engaging in micro-scale chemistry based practical learning activities.*

## 1. Introduction

A study that was conducted in the middle of 1990s to investigate the status of science teaching in Tanzanian secondary schools revealed that there were deep-rooted problems in the teaching and learning of science in the secondary education sub-sector (Chonjo, Osaki, Possi, & Mrutu, 1996). Problems in teacher pedagogical competence, curriculum, examinations, laboratories, equipment, and consumables were among the most prevalent in the report. The report revealed that teachers' pedagogical skills were weak, most teachers had inadequate practical skills or lacked competence, and continued to lecture, with a focus on the next examinations rather than promoting understanding. Access to regular In-service Education and Training (INSET) programmes for teachers to update their knowledge and teaching skills appeared to be limited.

Likewise, the syllabuses were overloaded with content while examination requirements compelled teachers to teach in a rush to cover the long syllabus. On laboratories, equipment, and consumables, the situation was reported as critical. Resources for practical work were reported to be very limited. Practical work was rarely happening in most schools because standard equipment and chemicals were too expensive to afford. Subsequent studies (Chonjo & Welford, 2001; Kibga, 2004; Leeuw, 2003; Mafumiko, 1998) showed that the situation in most schools did not significantly improve over time, especially in relation to resources and the conduct of practical work, shortage of science and mathematics teachers, as well as shortage of textbooks.

In view of these findings, the need for improvement of science and mathematics teaching in the country was seen as inevitable. Improving science teaching and learning materials (e.g. textbooks and laboratory facilities) in the schools and strengthening both pre-service and in-service science teacher education were considered priority areas for improvement efforts. Among the improvement strategies were the establishment of collaborative donor funded science education projects aimed at improving the teaching and learning of science and mathematics in the country (Osaki, Ottevanger, Uiso, & Van den Akker, 2002; Osaki, 2007). One of these projects was the Teacher Education Assistance in Mathematics and Science (TEAMS) project. The TEAMS project focused on science and mathematics teacher education, both pre-service and in-service, and worked mainly with undergraduates at the University of Dar es Salaam and A-level science teachers in Tanzania. Among the project activities were research and development of science teaching and learning materials, capacity building by training science education researchers and leaders (Ottevanger, de Feiter, Osaki, & Van den Akker, 2005). The Micro-Scale Chemistry Experimentation (MSCE) study reported in this chapter was thus carried out within the framework of the TEAMS project. The underlying assumption of MSCE is *less is more*: less cost, less demand on chemicals and equipment, less 'chalk and talk' teaching, for *more*: understanding, motivation, safety, and 'hands-on and minds-on' learning activities.

The aim of the MSCE study was to explore the possibility to use micro-scale chemistry approach as a means to perform practical activities in chemistry classes, hence reducing the need for highly equipped laboratories, but also providing opportunities for students to engage in a process of active learning. The essential characteristics and potential benefits of micro-scale experimentation in teaching and learning of chemistry are highlighted in the next section.

## **2. Theoretical underpinnings**

This section on theoretical underpinnings briefly explores micro-scale chemistry experimentation as promising intervention to improve teaching and learning practices of chemistry in Tanzania schools. This intervention was envisaged because of its characteristics as a low-cost small-scale approach to practical chemistry teaching. Also in this section, the role of exemplary curriculum materials to prepare and support teachers in the initial classroom implementation of micro-scale chemistry approach suiting their context has been considered as a promising strategy.

### **Micro-scale chemistry as a promising approach in chemistry teaching**

Micro-scale chemistry is an approach to performing chemistry experiments, which provides hands-on activities and personal experiences, where students have opportunity to do experiments individually. Experiments with micro-scale chemistry approach are conducted by using a reduced scale using small quantities of chemicals and often (but not always) with simple

equipment (Abdullah, Mohamed, & Ismail, 2007; Bhanumati, 1997; Rayner-Canham, 1994; Skinner, 1997). The advantages of micro-scale chemistry are numerous and well attested (Bradley, 1999; Rayner-Canham, 1994; Skinner, 1997). Such advantages are essentially related to *cost savings, improvement in laboratory safety and air quality, and environment-friendliness*. Beyond the economical, environmental, and safety advantages, micro-scale chemistry offers a number of pedagogical advantages (Abdullah, Mohamed, & Ismail, 2007; Mafumiko, 2006; Towse, 1998) including the following:

- It engages students in hands-on learning experiences and provides more opportunity for collaborative learning.
- Students gain confidence in their own ability to work with small amounts of materials.
- It is much faster to carry out, allowing students to accomplish much more in the laboratory.
- Students enjoy it because the dullness usually associated with laboratory work is reduced since students are not sitting around and waiting for something to happen.
- It instills in students the ethics of resource conservation.

The benefits of micro-scale in the context of developing countries are exemplified by only a small number of studies (Bradley, 2000; Thulstrup, 1999; Towse, 1998). The review by Towse (1998) on the micro-scale chemistry approach cites several studies of high school students from different contexts in which strong positive attitudes toward micro-scale chemistry were exhibited. Among the findings from these studies are: enhancement of student laboratory skills, more focus on understanding of the concepts rather than on the manipulation of equipment, more opportunity for discussion and reflections, experiments are easy and fun for students. The positive results of micro-scale chemistry from past studies seemed encouraging enough for Tanzania, where both human and material resources are inadequate in most schools.

### **Exemplary curriculum materials to support teacher learning**

Curriculum materials are educational resources, which are used to support the presentation of, and interaction with the curriculum content. Curriculum materials include educational resources such as textbooks, workbooks, teacher guides, manipulatives and modern technology-based materials. These materials whether supplied by instructional designers and curriculum developers, or publishers and researchers have traditionally been designed with student learning as a goal (Schneider & Krajcik, 2002).

Implementing curriculum reforms is a challenging task. It requires change in practice. Teachers need to learn new classroom practices and emerging teaching/learning techniques. They will benefit from support in terms of 'what to do' and 'how to do it effectively'. Although curriculum materials have traditionally been designed with student learning as a goal, materials can be designed to support learning by teachers as well as students (Schneider & Krajcik, 2002). Likewise, curriculum materials have a role in helping to initiate and sustain reform in science education because they are concrete and tangible vehicles for exemplifying the essential ideas of a reform (Powell & Anderson, 2002). In the MSCE study, a curriculum unit /module on solubility and solubility product consisting of a series of lessons designed on the basis of the Tanzanian A-Level chemistry syllabus and micro-scale experimentation techniques were considered an important vehicle for demonstrating the use of the MSCE approach to support teachers in the implementation of practical work in A-level chemistry classes.

According to Van den Akker (1988), exemplary curriculum materials should fulfill three main functions:

- provide clear understanding of how to translate curriculum ideas into classroom practice;
- provide a concrete foothold for the execution of lessons that resemble the original intentions of the designers;

- stimulate reflection on the teachers' role and any possible adaptations of the teachers' attitudes towards the innovation.

In addition, in his investigation on the role of curriculum materials to support teachers implement a primary science curriculum; Van den Akker (1988) identified areas of implementation problems, each of which could be addressed with the help of exemplary curriculum materials. These areas include: lesson preparation, inadequate teachers' background knowledge and confidence in the subject matter and skills; changing the teacher's role-all the more difficult and time-consuming because it involves the alteration of teacher's beliefs; and monitoring of student learning progress and outcomes. In view of these aspects, Van den Akker (1988) suggested creating materials with a large amount of '*procedural specifications*', that is, clear and specific guidelines for that part of the intervention to be implemented. These parts are apparently at risk of being not effective when it comes to implementation, and where teachers might be uncertain. The outcomes of his study indicated that curriculum materials helped teachers in the initial phase of implementation by providing procedural specifications. In this case, exemplary lesson materials were used as concrete aids to high school chemistry teachers first to familiarize themselves with the MSCE approach and second to implement micro-scale experiments with students for the first time with less support of an expert. Furthermore, in his study Van den Akker (1998) concluded that carefully designed curriculum materials could improve the implementation process and outcomes.

Similar other studies, involving development and use of curriculum materials in supporting curriculum reform efforts in secondary science education (in both developed and developing countries), have been reported. Schneider and Krajcik (2002) designed 'educative' curriculum materials, intended to support teacher learning as well as student learning. The materials incorporated information explaining science content for teachers beyond the level suggested for students; learning sets explaining the reasoning behind the sequence and flow of the lessons; short scenarios illustrating how an idea or activity may be introduced; help for using artifacts as assessment tools of the lessons; and notes to the teacher embedded within the lessons. Schneider and Krajcik found that teachers used the materials most during planning of lessons for their students. They also found that through the use of the curriculum materials teachers learned about Pedagogical Content Knowledge (PCK) for the specific lessons, which is also highly promoted by Shulman (1986). Voogt (1993) designed and evaluated teacher and student materials to support teachers in the use of courseware in an inquiry-based science curriculum in Dutch secondary schools. Whilst she found that teachers who used teacher materials kept their lesson approaches closer to the intentions of the designer of the curriculum, but they often used student materials for the preparation of their lessons. Voogt (1993) noted that teachers who used student materials performed considerably poorer in class than their colleagues who used teacher materials. From her findings Voogt (1993) argues that when the discrepancy between the normal classroom practices of a teacher and the proposed intervention is too big, exemplary teacher and/or student materials are in themselves not a sufficient aid for preparing and implementing the curriculum to a satisfactory level. The study by Van den Berg (1996), on the other hand, indicated that the integration of teacher support materials with procedural specifications into an in-service programme helped to stimulate teachers to try new ideas in their classrooms and provides successful first-time experiences. Van den Berg (1996) also observed that inclusion of procedural specifications made lesson preparation less complicated and less time consuming as compared to planning a lesson without them.

In the African context, especially Sub-Saharan Africa, several studies have successfully used curriculum materials as a strategy to support secondary science curriculum and teacher

professional development efforts. Ottevanger (2001) designed teacher support materials to help teachers implement a new science curriculum for junior secondary schools in Namibia. Ottevanger found that materials that incorporate procedural specifications on essential elements of the lesson provided adequate support for teachers in the initial phase of implementation of the new curriculum. Ottevanger reported also that the use of the materials as a part of in-service training programme enhanced effectiveness in supporting innovative reforms in science education. Studies by Tilya (2003) and Kitta (2004) investigated the use of exemplary materials as a strategy to support science and mathematics teacher professional development in Tanzania. Outcomes from these studies were largely positive and were in line with the findings reported by similar studies carried out in Southern Africa (Ottevanger, 2001; Stronkhorst, 2001; Thijs, 1999).

### 3. Research design and methods

The MSCE study was guided by the following overall research question: *What are the characteristics of micro-scale chemistry curriculum materials so that they contribute to the implementation of effective practical work in chemistry teaching in Tanzania schools?*

An overall design of the MSCE study to answer this main research question is presented below. An overall design of the study was set out in order to answer the above stated research question. It comprised of three phases including; front-end analysis, development of prototypes (design and formative evaluation) and field-testing of the Micro-Scale Chemistry Experimentation approach as presented in Figure 1.

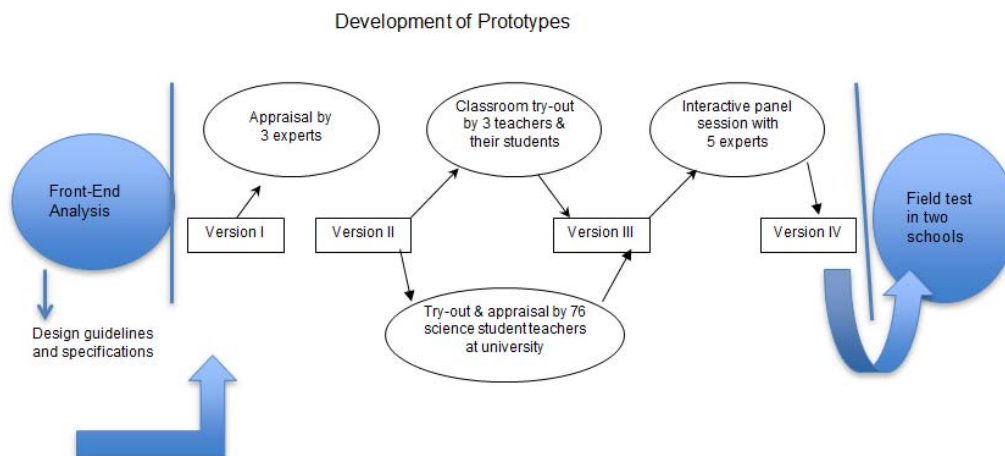


Figure 1: Overall research design of the MSCE study

The first phase, front-end analysis, included a context analysis and a literature review. The context analysis sought to gain insights into the situation of teaching and learning science in Tanzanian secondary schools with particular attention to implementation challenges of chemistry practical work. The literature review aimed at gaining insights to micro-scale chemistry as a promising example of low-cost methods for implementing and promoting practical work in chemistry teaching. Information generated from the context analysis and literature helped in the formulation of preliminary design guidelines and design specifications (as described in the next section below) for the development of MSCE approach.

The second phase involved development of prototypes of MSCE exemplary curriculum materials. In this stage, a succession of prototypes was developed through the cyclic approach



of analysis, design, development and formative evaluation activities (Nieveen, 1999; Van den Akker, 2002). The formative evaluation (carried out via expert appraisals and classroom try-outs) aimed at increasing the quality of prototypes. Evaluation of the first version puts emphasis on obtaining indications for the improvement of validity and practicality of the intervention (Mafumiko & Ottevanger, 2004; Nieveen, 1997; 1999), while in the evaluation of the subsequent prototypes the emphasis shifted to practicality and effectiveness of the MSCE approach. The third phase of the study focused on the effectiveness of the intervention (see key reference for example of final version of the materials). In this phase a quasi-experimental research approach, non-equivalent control group design (Creswell, 2002; Mertens, 1998) was used to evaluate the initial impact of micro-scale curriculum materials on student learning of a specific syllabus topic as compared to the approaches teachers normally use in teaching the topic.

### **Design guidelines**

In view of the information obtained from the context analysis and literature review, seven preliminary guidelines were formulated to guide the design and formative evaluation of lesson prototypes (teacher and student exemplary materials) for MSCE approach.

1. *Active learning through micro-scale chemistry experimentation*  
Focusing on learner-centred approaches and learning for understanding, exemplary curriculum materials were designed with the aim to engage students actively in the learning process through both hands-on and minds-on practical work.
2. *Simple forms of practical work*  
Practical activities designed with the MSCE approach should be simple to carry out and should not largely depend on an expensive modern laboratory.
3. *Science (chemistry) learning goals*  
Specification of the intended learning outcomes the designer (or teacher) has in mind for students is an important factor to consider in designing effective practical work (Eijkelhof, 2002; Millar, Le Marechael, & Tiberghien, 1999).
4. *Content and pedagogical support*  
Reflecting on the challenges Tanzania secondary chemistry teachers' face in terms of content and pedagogy as revealed in the context analysis, exemplary curriculum materials intended to support teachers with the implementation of the MSCE approach were designed with adequate support for discipline specific subject matter knowledge and teaching strategies learning.
5. *Alignment with current curriculum*  
Exemplary curriculum materials designed and developed must support the teaching and learning of the existing curriculum. Materials that do not fit into the existing curriculum are likely to make teachers lose interest and adopting the MSCE approach for use in their teaching might be difficult. Users (teachers) of the materials must believe that the materials will become part of the established curriculum and that it is not a waste of time. In this way legitimacy of the new approach could be established.
6. *Fit with the school time table*  
To enable classroom-based activities to be carried within normal classroom/ laboratory settings, exemplary curriculum materials were designed with lesson activities that can be carried out within periods allocated for practical work (2-4 periods of 40 minutes each) prescribed for the Tanzanian A-level science curriculum.
7. *Flexible and active learning environment*  
Experiments designed with the MSCE approach should be possible to perform/ conduct in both normal classroom and in a modest science school laboratory, but not necessary with expensive glassware and modern equipped science laboratory.

### Design and formative evaluation

Based on the design guidelines described above concrete design specifications (Table 1) for teacher support materials were developed. These specifications formed the input for the first prototype (version I in Figure 1): the first four exemplary lessons of 80 minutes duration (or two periods of 40 minutes each) were designed and developed to cover the main subject intended to be taught for the topic syllabus of solubility and precipitation. Through evolutionary prototyping other prototypes were developed (Figure 1, versions II to IV). In Table 1 specific areas of support (first column) for teachers in implementing MSCE lesson materials and detailed description of design specifications for the lessons reflecting the tentative design guidelines are provided.

Table 1: Design specifications of exemplary teacher support materials

Area of support	Design specifications
Lesson preparation	<p><i>General description of lesson provides:</i> Description of what the lesson looks like: provide the general overview of the lesson; objectives of the lesson, which indicate learning outcomes expected to be achieved by the students at the end of each lesson. References to resources for further reading: suggests possible textbook and chapter that teachers can refer for more content information and student assignments.</p> <p><i>Lesson preparation consists of:</i> Lesson plan and timing: suggests time for each lesson stage and the learning activities. Materials required for the lesson and possible alternative if not available. Specific information on reagents preparation. Necessary safety precautions on toxic chemicals. Possible problems (and how to deal with) students may encounter during the lesson</p>
Subject matter and pedagogical content knowledge	<p><i>Subject content provides:</i> Suggestions for questions for pre-lab exercise to help teachers explore students' prior knowledge and to provide students with an idea about the practical they are going to do. Adequate and accurate notes on what students are expected to be taught and learn. Examples of students' questions and answers. Short explanation of key chemical concepts in the lesson.</p>
Teaching methodology (pedagogy)	<p><i>Teaching strategies, provides:</i> Concrete suggestions for the role of teacher during lesson execution. Suggestions for grouping: to guide teachers in using groups for practical work and small group discussion to promote student active participation in the lesson. Suggestions on how to hand out equipment and how to collect them. Suggestion on how to try-out experiments beforehand: to ensure reagents are functioning well for a particular experiment. Sequencing of learning activities, including pre-lab and post lab discussions.</p>
Assessing student learning	<p><i>Learning effects</i> Suggestions for data analysis and concept development questions, small group presentations and test questions. Suggestion for homework questions.</p>

#### **4. Formative evaluation of MSCE exemplary lesson materials**

As presented in the overall design of the study in Figure 1 the formative evaluation of the MSCE lesson materials was carried out through a cyclic process of expert individual appraisals, classroom try-out, and interactive panel session with experts.

##### **Individual expert appraisal**

Individual expert appraisal was mainly on the first version (prototype) of the lesson materials. Aiming at exploring on the validity of the lesson materials and the MSCE approach, four experts (two local & two international) in chemistry content and pedagogy as well as curriculum materials development were individually consulted to provide their views on the materials in writing and through one to one discussion.

##### **Classroom try-out**

Following revision of the first version of the lesson materials, the second cycle of formative evaluation activities involved try-out of the second version of lesson materials with three A-Level chemistry practicing teachers and 102 science students studying chemistry as one of their principal subject in their combination. All participating teachers were purposively selected because they were currently teaching the chemistry subject in the school. They were all possessing Bachelor Science with Education degree and had reasonable teaching experience ranging from 4 years to 25 years. Thus, they were expected to provide the valuable information regarding introduction of the MSCE approach in practical chemistry teaching in Tanzania secondary schools. Also the classroom try-out involved 76 university science students who were in the final of their studies prepared to become A-level chemistry teachers

The main aim of the try-out was to explore the validity and practicality of the MSCE approach in the intended user actual settings. It specifically intended to find out whether the teachers were able to use the exemplary materials to implement the MSCE approach with their students in class as intended by the designer. It also aimed at examining whether the approach engaged learners actively in learning chemistry and whether both teachers and students found it relevant or not relevant in their situation. Data from classroom try out were generated through classroom observation, focus group discussion, and student questionnaire.

##### **Interactive panel session with international experts**

Following classroom try-outs and revisions a third version of the lesson materials consisting of five lessons was produced and reviewed in preparation to field testing of the Micro-scale chemistry approach. The main focus of the review of the MSCE lesson materials by experts was to gather information on the overall quality of the materials toward final improvement for use in the field test (version IV, Fig. 1). Five international experts with experiences in chemistry teaching, curriculum materials design and research with African exposure (some with Tanzanian exposure) all purposively selected from four Universities in the Netherlands were pre-exposed to the materials. These experts were run through (walked through) the MSCE based lesson materials by the materials developer and researcher in an organized interactive panel discussion session.

#### **5. Results of formative evaluation**

Formative evaluation by individual experts and interactive panel session results revealed that overall; layout of lesson materials was good with most of the experiments presented clearly in both teacher support materials and student worksheets. Experts' comments indicated that the materials were relevant and appropriate for the grade level they were designed. They also felt

that the information for the teacher on how to check student learning progress was adequately given in the materials. Apart from their positive comments, experts observed some important components of the materials that needed improvement to enhance the quality of the prototypes:

- There was an underestimation in timing of learning activities, such as lesson introduction and small group presentations for some lessons (e.g. lesson 1).
- Procedural specifications on how the lessons will be executed in class and what roles teachers and students should play during the lesson were not adequately provided in the teacher support materials.
- An opportunity to explore students' understanding of key chemical concepts (such as ions, cations, anions, soluble, insoluble, diffusion) in the different lessons needed to be provided at the beginning of the lesson or explained thoroughly at the end of each lesson.
- Lesson summary and pre-laboratory exercises in some of the student worksheets provided answers to the students' questions beforehand. Experts felt that these were preempting student thinking about the experiments and exercises they were going to do.
- To increase learners' involvement and participation all teacher demonstration experiments were suggested to be re-designed for students own experiments because it would be difficult for students to watch a demonstration done on micro-scale.

Overall, the design specifications of micro-scale chemistry based lesson materials as demonstrated by both teachers and students helped them to engage in hands-on and minds-on interactive lessons and made the MSCE approach valid and feasible in their circumstances. Through student questionnaire and teacher interview responses it was revealed further that the design specification presented the micro-scale chemistry experiment approach in a simple but effective manner, whereby students are actively engaged in the learning process and appeared to enjoy their chemistry lessons. The key characteristics of the exemplary curriculum (lesson) materials generated from the design specifications are presented in detail in the key reference (Mafumiko. 2006). These include explanation for the teacher, lesson preparation aspects, subject matter and pedagogical content knowledge aspects, teaching strategies, monitoring and assessing student learning and self-instruction student worksheets.

The results from the classroom try-outs showed that the teacher support materials and the student worksheets designed for micro-scale chemistry practical work demonstrated some potential of its validity and practicality in the circumstances they will be used. Teachers found that the materials provided adequate support information during the preparation of students' practical work with the MSCE approach. Teachers from both schools demonstrated that they were able to use the materials to prepare and successfully try-out the experiments before bringing to the class. An observation on initial successive experience of teachers to use the micro-scale approach during the preparation session is that teachers got excited to tryout the materials in their class with students.

Teachers' general impressions on the materials as used in the class indicate that teachers found the materials and the MSCE approach very useful. They stated that the materials presented the approach in a simple but effective manner. The materials cover most of the content as specified in the chemistry syllabus, and provide ample opportunity for students to be actively engaged in practical activities. Moreover, teachers indicated that the new approach needed less time, not sophisticated equipment and can be carried out during theory lessons and in ordinary classrooms (not necessarily in laboratories). Teachers indicated that the approach could also be useful in lower forms at O-level. On the other hand, teachers observed some deficiencies and suggested for amendment mainly in the area of the contents of the

lessons compared to the syllabus outline and the timing of some of the components of the lessons.

Initial students' experiences indicated that they were excited by their involvement in the micro-scale chemistry lessons. Mostly students stated that they enjoyed doing the practical (mixing drops and observing color changes) by themselves and the cooperation from the classmates and the teacher. They indicated that their teachers had been much friendly during the lessons. They also commented on how little time the experiments had taken. Likewise some students stated that they started to like and to understand chemistry.

In conclusion revisions of different versions (lesson prototypes) and the design specifications enhanced the quality (acceptability, local relevance, feasibility, effectiveness) of the Micro-scale chemistry intervention in the study schools, hence providing indications for validity, practicality and effectiveness of the approach in Tanzanian schools.

## 6. Summative evaluation

The final version of the Micro-Scale Chemistry lesson materials was field tested in real target user settings (i.e., with teachers and students in their schools) in order to evaluate the effectiveness of the MSCE approach. The field-testing of the approach intended to answer the following main research question:

*What is the impact of the MSCE approach on teaching and learning chemistry in Tanzanian A-Level classes? Along with this question three sub-questions guided the summative evaluation phase:*

1. *How is the MSCE approach actually implemented in the actual classroom setting?*
2. *What are the teachers' opinions on Micro-scale Chemistry Experimentation based lessons?*
3. *What do students experience and learn from the MSCE approach?*

### Participants and setting

In the summative evaluation the effectiveness of the Micro-Scale Chemistry Experimentation approach was studied in actual school settings with real students and their regular teachers. Two schools were involved in each region, one school designated as an experimental group and another as a control group. These schools were purposively selected based on: (1) the willingness of chemistry teachers to participate in the MSCE study, commitment and cooperation of school administration to accommodate the study established during pre-field test visits, (2) availability of at least two classes or one class of 50 Form 5 students studying Physics, Chemistry and Biology (PCB-stream), (3) match of teachers' schemes of work to the topic of intervention, and (4) reliable means of transport to the regions and schools. The study schools were similar to most senior government secondary schools in Tanzania.

A total of 195 science students, 145 male and 50 female enrolled in Form 5 (13<sup>th</sup> grade, 17-18 year old) science classes from four selected government secondary schools participated in the study. Out of the 195 students, 107 came from the control schools and were all boys. 88 students including 38 male and 50 female came from the experimental schools. It can be noted that the students' sample had an unequal distribution of boys and girls between the experimental and control classes. There were fewer girls than boys and all were all were in the experimental group. However, this unequal distribution by sex favoured the control group in view of other study findings (Urassa & Osaki, 2002).

Participating teachers one at each school were those who were teaching the study classes. All the four teachers were male with chemistry teaching experience at A-level ranging from 1 to 2 years. These teachers had the same level of training (Bachelor degree) with most experienced teachers in same or similar schools in the country. However, they were more motivated to experiment the approach using the MSCE design based exemplary lesson materials because of its friendly user characteristics and level of support.

*Data collection methods and instruments at summative evaluation*

An overview of the data collection methods is presented in Table 2.

*Table 2: Data collection methods*

Research theme	Data collection method						
	Experimental group					Control group	
	CO	IT	ST	SQ	IS	CO	ST
1. Classroom implementation	√					√	
2. Teachers' opinions		√					
3. Student learning			√	√	√		√

*Note:* CO: Classroom Observation; IT: Interview with Teachers; ST: Student pre- and post-achievement tests; SQ: Student Questionnaire; IS: Interview with Students.

Classroom observational data in the experimental classes were obtained with the help of a curriculum profile (Van den Akker & Voogt, 1994), developed by the researcher, with some items adapted from Ottevanger (2001) and Tilya (2003). The focus of the curriculum profile was mainly on the features of MSCE exemplary teacher and student materials including elements such as pre-lab exercises, small group practical activities, discussion and reflection on experimental results, and consolidation of learning outcomes. The profile comprised of action statements organized under: introduction of the lesson, body of the lesson and the conclusion. Therefore direct classroom observations was conducted and aimed at observing how teachers and students were using the materials and the MSCE approach in their context. Classroom observations in the control classes aimed at gaining insights into the classroom implementation of solubility and precipitation lessons using the regular 'traditional' teaching methods. The observations were guided by the same curriculum profile used in the experimental classes but considered only items applicable to the lessons. In addition, notes were also taken during the lessons to provide a descriptive summary of the classroom activities.

Interview with teachers was conducted to collect data on their experiences with and opinions of the MSCE approach, reflecting their views from the preparation phase to the actual use of micro-scale experiments in class. The achievement test consisted of 13 multiple-choice items and two short-answer items, constructed with a focus on practical knowledge and skills likely to be demonstrated by students with Micro-scale chemistry exposure, and less theoretical aspects. Prior to administration, two university lecturers validated the achievement test through a review with expertise in chemistry and chemistry education and one experienced A-level chemistry teacher. The test was also pilot-tested in one A-level secondary school with few students of the same grade level as students in the study schools. The reliability of the test was estimated based on the multiple choice item responses and turned out to be quite low ( $\alpha = 0.51$ ). The reliability of short answer items was 0.69. However, analysis on the test results focused mainly done item basis attempting to explore the impact of MSCE based lessons on student learning, from which seven items appeared to directly have an effect.

To assess student experiences and opinions about the MSCE based chemistry lessons all students were invited to respond to a semi-structured questionnaire at the end of the classroom implementation of the MSCE approach at each experimental school. The questionnaire consisted of 27 close-ended Likert scale items and three open-ended items. The open-ended questions focused on what students liked and/or disliked about the MSCE approach, and whether they experienced any difference between MSCE-based lessons and the 'regular' chemistry lessons. An estimation of the internal consistency (Cronbach's alpha) of the questionnaire based on the close-ended question items was found to be 0.78. This reliability result of the questionnaire instrument, mean that self reported views or opinions presented true experiences of the students on micro-scale experimentation, which was vastly positive.

## 7. Findings and discussion

In general, the results of the summative evaluation show that both teachers and students had positive experiences with the micro-scale chemistry experimentation approach. They both liked the approach, were to a large extent able to implement it in class, and found the approach helpful in facilitating their teaching and learning of chemistry.

Results from classroom observations show that the use of micro-scale practical activities promotes an active learning environment. It provides opportunities for student-student interaction by allowing more time for discussion and reflection as actual performance of experiments is completed fast. Classroom observation results also revealed that conducting practical work through micro-scale approach fosters cooperative learning elements among students as well as stimulating students' interest in the subject. Teachers' interview responses about the MSCE approach indicated that they found experimenting on a micro-scale approach an interesting and useful for conducting practical work with students. The approach provided them the opportunity to do practical work with large numbers of students using minimum resources and had a great potential to engage students actively in the learning process through small group activities. Teacher reflections also indicated that their exposure to micro-scale chemistry techniques enhanced their subject matter knowledge as well as practical skills.

Results from questionnaires and interviews show that the majority of students experienced lessons conducted with MSCE practical activities very positively. Most students seemed to like the MSCE approach because it is simple, interesting, and makes them enjoy chemistry classes and learn more about the subject. Apart from being simple and interesting, students appreciated the opportunity to do practical work in the MSCE based lessons as compared to normal lessons, which are normally taught without practical work. Students felt that with micro-scale chemistry experimentation they were actively involved in the learning process. Apart from helping them understand more about chemistry and increase their confidence in practical work, students indicated that the experiments and follow-up questions were challenging and made them think critically. These results suggest that MSCE activities can be used as vehicle to promote thinking skills among students.

Comparison of student pre-test and post-test results at item level between the experimental and control classes, revealed two patterns of student achievement with regard to the chemistry subject matter and skills studied during the MSCE intervention, that is, solubility and precipitation or solubility and solubility product. Students who studied the topic with exposure to MSCE practical activities (from two experimental groups) showed higher learning gains in items related to application and analysis of chemistry principles than students who studied the topic by regular methods. On the other hand, students who studied the topic by regular methods

performed significantly better in factual knowledge items than the experimental group students. The fact that students who were not exposed to MSCE approach performed better in some items it implies achievement test alone could be an inadequate instrument to measure cause and effect, when the intervention involves actual performance of experiments. Nonetheless, this aspect was addressed by the student questionnaire and focus group discussion.

Apart from the positive responses of both teachers and students to the MSCE approach, there are some concerns about classroom implementation. Some students felt that conducting experiments on the surface of the plastic sheet was not safe, since the technique exposes students to many chemicals at time, some of which are toxic and might have an undesirable effect on their health. Similarly, students felt that there was the possibility of further reactions due to air, contamination between different reagents due to small boxes, and hand contamination unless great care was observed. These findings suggest that although the approach appears to be effective in promoting student active learning and love for chemistry, safety issues and the nature of the chemicals used in the experiments might need a review.

## **8. Reflections on educational design (developmental) research approach**

As outlined earlier in this chapter, the MSCE study adopted a developmental (educational design) research approach, an approach that allows the realization of promising small-scale examples of interventions and generation of methodological guidelines for the design and evaluation of such interventions (Van den Akker, 1999). Accordingly, reflection on this approach was thought important to see if it provided an opportunity for designing an intervention with local relevance. Reflection on the approach meant also to re-assess opportunities for better understanding of local implementation conditions and the difficulties or tensions teachers as well as the researcher (such as researcher's multiple roles in the research process) might have experienced in the future improvement of the intervention.

### **Researchers' multiple roles: Maintaining balance and minimizing conflicts**

One of the benefits of the developmental research approach adopted in this study was that it stimulated the researcher to learn and perform a number of (new) roles including designer-developer, facilitator, and evaluator-researcher. In the development of exemplary lesson (curriculum) materials the researcher was the designer, in the introductory workshop he took the role of facilitator, and in the classroom he was a researcher (observer). As a designer the researcher aimed at developing high quality materials, as facilitator at ensuring that teachers were adequately introduced to the intervention, and as a researcher at being objective. These roles were essential in order to develop and evaluate the intervention (the micro-scale chemistry practical approach). Playing multiple roles was sometimes beneficial (getting immediate feedback on workability of design specifications, opportunity to support teachers and students in areas they struggle with the intervention) but also created problems in the research process. An example of such problem was the tension over the dual roles of the researcher-facilitator during classroom observations. Teachers as well as students often asked for clarification of some aspects of the lesson activities and the researcher needed to maintain his role as researcher. From the classroom observations we learned that teachers needed more support or coaching during classroom implementation of the new approach. This classroom practices suggests that the use of an external evaluator would be a better strategy for an objective assessment of classroom practices with the new approach, and we strongly recommend for researchers adopting or adapting use of curriculum profile in conducting classroom observation in studies of this nature.



However, being a designer of the exemplary MSCE curriculum materials and an observer of how teachers and students were implementing the new approach in their classes could have positively influenced participant teachers' classroom performance due to 'the Hawthorne effect' (Krathwohl, 1998). Krathwohl cautions that people tend to increase their effort and motivation when being watched or evaluated while implementing a new system aiming at improving their performance, even if the new method is no better than the old way of doing things.

Combining these roles, the researcher could have also made an overly positive interpretation of data gathered from questionnaires and interviews. To address these dilemmas, Van den Akker (2002) suggests the use of multiple methods and sources of data collection as well as discussions with all parties involved in the development for deeper understanding, stronger commitment, and for reaching careful and balanced conclusions. To reduce the possible bias of the results, the present study employed triangulation of methods classroom (observation, interview, questionnaire, and achievement test) and sources of data collection (Cohen, Manion, & Morrison, 2000; Krathwohl, 1998).

### **Lessons learned**

The MSCE study was set up to design and evaluate a micro-scale chemistry scenario designed with five exemplary lesson materials as the support structure that could assist teachers with the implementation of more practical work in A-level chemistry classes. The following conclusions can be drawn from the findings of this study:

- The use of curriculum materials as a vehicle greatly helps teachers implement the MSCE approach in their classrooms. Procedural specifications on critical aspects of the curriculum enable teachers to work with and learn about the MSCE approach without an extensive initial orientation and /or consultations.
- A properly designed worksheet with concise and clear information about the practical lessons (simple in experiment reaction layout, stated purpose of experiment, group organization, reflective questions, pre- and post-laboratory exercise, with predict-observe-experiment and discuss model) provides enough structure and support for groups of students to carry out micro-scale experiments without the constant intervention of the teacher.
- The positive results show that the micro-scale approach can be successful in facilitating implementation of practical work in resource-constrained classes. This is because the MSCE approach employs small amounts of chemicals and cheap apparatus, and hence is affordable to most schools, and some of the required materials, e.g., plastic sheets and pipettes are locally available.
- Teachers' role in monitoring student learning progress is essential for ensuring success in the implementation of the micro-scale chemistry practical work. Although participant teachers implemented the MSCE approach relatively successfully in introducing pre-laboratory exercises, group organization, and guiding students through the practical activities, they had great difficulty in keeping time for small group discussion. This resulted in less time for groups to present their ideas to the whole class and receive feedback from classmates and teacher.
- Educational design research approach though relatively uncommon offers researchers and practitioners (teachers in the case of MSCE study) the opportunity to produce interventions of real value-tools, approaches, theories, and products tested in the field and shown to be effective.

The major result of the MSCE study has been to introduce promising ways to motivate the teaching of chemistry in A-level chemistry classes in Tanzania. Overall, it can be concluded that the MSCE approach is a powerful method to change teaching and learning practices in chemistry classrooms. The materials need only short introduction, are easy to use, engage learners actively in the learning process, foster positive classroom interactions, promote positive student attitudes toward chemistry, and provide more opportunities for developing thinking skills and understanding better basic concepts in chemistry. Nevertheless, reflecting from the review of the researcher's role during the study reported in this chapter, a further study on the impact of the MSCE approach and investigation on the conditions under which this approach leads to effective teaching and learning of chemistry in Tanzanian schools is highly recommended.

### Key source

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## Behavioural Biology: Developing a Learning and Teaching Strategy in Upper Secondary Education

Anco van Moolenbroek & Kerst Boersma

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# 29. Behavioural biology: Developing a learning and teaching strategy in upper secondary education

Anco van Moolenbroek & Kerst Boersma

## Abstract

*The aim of the study is the development of an adequate learning and teaching (LT-) strategy for behavioural biology that increases students' conceptual development of the subject behaviour. The study is one of a number of design studies conducted in the last decade that contributes to a preliminary design theory for context-based biology education. The design of the study consists of an explorative phase, and two cyclic research phases in which eight case studies were conducted to test the LT-strategy in the classroom. The conceptual framework underlying the study originates from behavioural biology and two pedagogical approaches (the concept-context approach and the problem posing approach). In the study, the concept-context approach and the problem posing approach are integrated in a single pedagogical strategy. Both sources (behavioural biology and pedagogical approaches) resulted in a set of design criteria. The analysis of the data, (e.g. interaction in class discussions and students' concept maps), showed that the LT-strategy structures students' conceptual development. Furthermore, students are able to reason from the perspective of a behavioural biologist. It was concluded that the use of authentic contexts, interactions, and motives stimulates students' motivation, providing for relevance and coherence. An LT-strategy could be constructed with the concept-context approach and the problem posing approach.*

## 1. Introduction

In current upper secondary biology education in the Netherlands, behavioural biology is generally a subject of less curricular importance, and it is isolated from other domains of biology. Furthermore, the most frequently used textbooks present examples of animal behaviour from the 1950's to the 1970's. Tinbergen formulated four questions in order to distinguish the function, development, causes, and evolution of behaviour (Tinbergen, 1963). It was noticed that biology textbooks did not show the dynamic and complex nature of behaviour, lacked references to modern behavioural biology, and did not structure behavioural biology according to the four questions of Tinbergen. From the analysis of the Dutch biology text books it was concluded that the behavioural biology presented to students in upper secondary education is out of date and that students do not have the opportunity to acquire an understanding of current research in behavioural biology. The societal relevance of behavioural biology appears from its contribution to animal welfare, the conservation of species, and the understanding of human nature.

In current biology education, three main problems were recognized, namely an overloaded curriculum, minor relevance to students, and a lack of curricular coherence. These observations coincided with recommendations of the Royal Netherlands Academy of Arts and Sciences (KNAW) to the Minister of Education to adapt the examination programs in upper secondary biology education to the current state of biology in society and research, focussing on students' development of biological key concepts. Following this recommendation, the Minister of



Education established a Board for the Innovation of Biology Education (CVBO) with the task to develop new examination programmes for upper secondary biology education.

The Board elaborated a coherent and actual learning line for biology education, with the conviction that the so-called concept-context approach could provide an important contribution to the solution of the three main problems. (Boersma, van Graft, Hartevelde, de Hullu, van den Oever, & van der Zande, 2005). The concept-context approach is an approach for selecting learning goals and organizing knowledge. Contexts have a dual function: relating scientific concepts to contexts and improving the relevance of the science curriculum by selecting contexts that have relevance for the students. Consequently, it was welcomed that some research studies could be conducted to address these challenges.

The study presented here focuses on the innovation of behavioural biology education, based on the concept-context approach for biology education and it therefore aimed to develop a domain-specific learning and teaching strategy (LT-strategy) for behavioural biology and to provide empirical support for the concept-context approach for biology education. An LT-strategy is a sequence of learning and teaching activities aiming to attain previously defined learning outcomes. An LT-strategy is generally domain-specific.

In the advice of the CVBO to the Minister of Education, including proposals for new examination programs, it was also indicated that the implementation of the new examination programs for upper secondary biology education would require in-service training of biology teachers on the elaboration of the concept-context approach in the biology classroom. It was argued that it would be desirable to support the implementation with outcomes of educational design research. Therefore, a number of design studies conducted in the last decade was summarized and integrated into a preliminary design theory for context-based biology education. It was expected that the design study presented here would contribute to such a design theory. In addition to the actualizing of the behavioural biology education and the development of a domain-specific LT-strategy, its third aim is therefore to contribute to a design theory for context-based biology education.

The primary aim of the study is, however, the development of an LT-strategy for behavioural biology. The research question of the study is as follows:

*What are the characteristics of an adequate learning and teaching strategy for behavioural biology in secondary education that increases students' awareness of behaviour?*

The design study presented here has been published before as a PhD-thesis (Van Moolenbroek, 2012).

## **2. Conceptual framework**

The conceptual framework underlying the study originates from two sources, behavioural biology and the theory on learning and teaching underpinning the concept-context approach and the problem posing approach. Both sources resulted in a set of design criteria.

### **Behavioural biology**

Today behavioural biology is a broad, integrative academic domain in which physiology, genetics and psychology are integrated with former ethology. This integration with other domains has several implications. First, it implies that behavioural biology does not focus any more at animal behaviour only, but also on human behaviour. Second, it implies that not only the organismal and population level of biological organization are involved, but also the cellular and molecular level. Research on behavioural biology has many practical implications in domains such as animal welfare and human nature. In spite of these two points, the basics for understanding the emergence of behaviour is still found in an early study of Tinbergen (1963),

in which four perspectives on behaviour are distinguished: causation, development, function, and evolution. These four perspectives can be considered as the key concepts of behavioural biology.

From these characteristics of current behavioural biology, the following domain-specific design criteria were derived (Van Moolenbroek, 2012):

1. An LT-strategy should include links with other biological disciplines such as physiology, genetics and psychology.
2. Students should be aware that behaviour is emerging from multiple causes, attributed to different levels of biological organization, in the interaction of the organism with its environment, and consequently requires an LT-strategy that includes systems thinking.
3. An LT-strategy should follow the structuring of concepts by the perspectives of causation, development, function and evolution of behaviour.
4. An LT-strategy should pay attention to the social relevance of behaviour biology in order to develop students' understanding of its relevance.

### **Theory on learning and teaching**

The theory selected for the development of design criteria for the didactical component of the LT-strategy is the theory underpinning the concept-context approach, an earlier design study on ecosystems behaviour based on the concept-context approach (Westra, 2008), and studies on the problem posing approach (e.g. Klaassen, 1995; Knippels, 2002).

The design study takes explicitly a learners' point of view. The learning environment, including the teacher, is supposed to structure students' learning processes, and to provide support. That implies that the role of the teacher is conditional, although it is derived from students' supposed learning processes. Therefore, an LT-strategy consists of a sequence of LT-activities that facilitates students' uninterrupted learning.

The concept-context approach for biology education is inspired by cultural-historical activity theory (e.g. Vygotsky, 1978) and situative approaches (e.g. Lave, 1988), and has the following characteristics (Boersma et al., 2005; Boersma, 2011).

To favour students' understanding of the relevance of biology it is recommended to present biological content in context. The understanding of biology's relevance, however, can only be developed if students experience that biological knowledge is used in society. Furthermore, if students experience that biological research has the potential to cope with some of the big issues of the 21<sup>st</sup> century, such as health, sustainability, food provisions and energy supply. For a better understanding of the relevance of biology, a context is redefined as social practice (van Aalsvoort, 2004). A social practice is defined as a number of participants performing a common, goal-directed activity, by means of tools (such as instruments, symbols, knowledge), according to implicit and explicit rules. The biological knowledge used in a social practice is functional in that specific practice and may differ from the biological knowledge in other social practices. An illustrative example of a concept showing different meanings in different practices is the concept cellular respiration (Wierdsma, 2012).

Considering the large amount of biological terms used in biology education, according to Ausubel's theory (Novak & Gowin, 1984), it is recommended to structure biological knowledge hierarchically, and to focus on students' development of superimposed or key concepts. Since a key concept may structure a large body of (biological) knowledge, it can be expected that it will be used in a diversity of social practices. However, since the meaning of biological knowledge is context-specific it can be expected that a concept will have different meanings in different social practices. Consequently, a student familiar with the meaning of a concept in a first practice has to adapt it when invited to apply it in another practice. This process is called recontextualisation (Van Oers, 1998) and implies a redefinition of the concept 'transfer'.

The problem posing approach, initially developed for physics education (Klaassen, 1995; Lijnse & Klaassen, 2004), is a pedagogical strategy aiming at the development of students' content-specific motives, in such a way that students are aware what they are doing and why, and have the confidence that they can accomplish their aims. Generally, a design is focusing at the interactive development of a central steering question that may be answered by performing one or more tasks. After the performance, the students are invited to reflect on the tasks and evaluate if the question can be answered. If not, a new task and or an additional question is developed; this procedure is continued until the steering question can be answered. In the study presented here, the concept-context approach and the problem posing approach are integrated in a single pedagogical strategy (Figure 1).

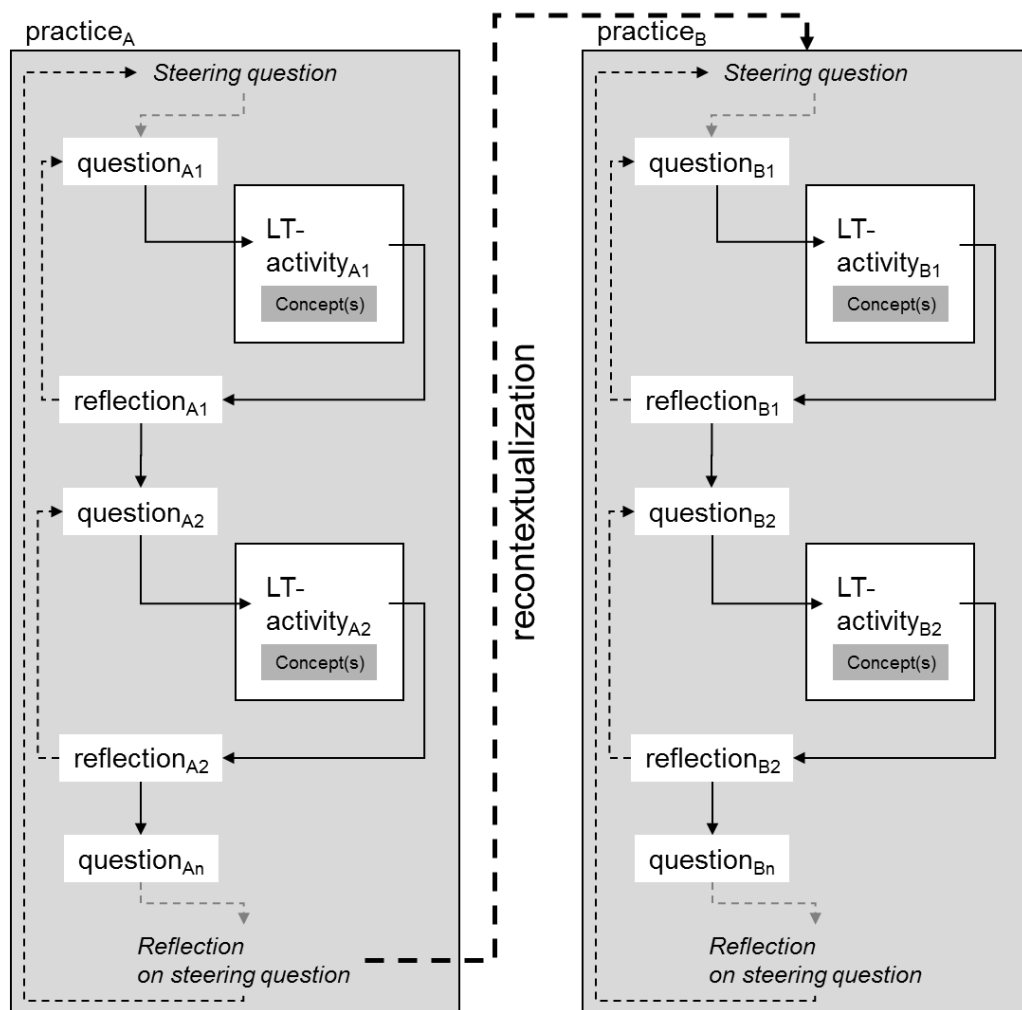


Figure 1: Integration of the concept-context approach and the problem posing approach (Van Moolenbroek, 2012)

Considering the concept context approach and the problem posing approach the following pedagogical design criteria on learning and teaching were articulated:

1. An LT-strategy for behavioural biology should be based on behavioural biology concepts used in authentic social practices. Students should have the opportunity to explore the personal, societal and/or scientific relevance of the selected behavioural biology concepts.

2. Participation in a social practice implies learning as the outcome of interaction between a person and its environment. An LT-strategy for behavioural biology must promote interaction between learners and their learning environment.
3. Learning activities aim to promote the thinking processes of the students. Therefore, an LT-strategy for behavioural biology should evoke motives. The sequence of LT activities should provide a storyline and create opportunities for non-interrupted learning, which supposes a sequence of motives for learning.
4. Recontextualising of earlier acquired concepts should be incorporated explicitly in the LT-strategy. That implies that an LT-strategy should include more than one realistic context.

Considering the design criteria for behavioural biology, the following intended learning outcomes were determined. Students should be able:

- a. to explain that behaviour is caused by internal and external factors,
- b. to describe that behaviour is the result of the interaction between the organism and its environment,
- c. to determine the function of behaviour,
- d. to describe the development of behaviour,
- e. to recognize the stress mechanism in the behaviour of humans and animals,
- f. to carry out a simple behavioural research (only at pre-university level),
- g. to discuss applications of behavioural research in vocational and scientific social practices.

### 3. Design and methodology

#### Design of the study

The design of the study consisted of an explorative phase, and two cyclic research phases in which eight case studies were conducted (Figure 2).

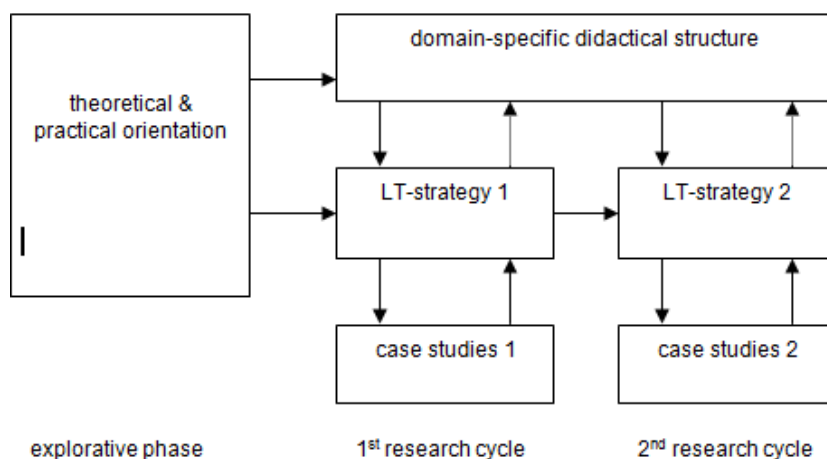


Figure 2: Design of developmental research (after: Boersma, Knippels, & Waarlo, 2005)

In the explorative phase, a literature study was conducted on behavioural biology, on behavioural biology in textbooks, current school practice, student understanding of behaviour, and current ideas on learning and teaching. The research activities resulted in the design criteria presented in the preceding section. In the first research cycle, a design of a preliminary LT-strategy was constructed, taking into account the design criteria. The LT-strategy consists of a sequence of LT-activities and is elaborated into a scenario that describes the LT-activities of

the teacher and the students. A scenario hypothesis and theoretically justifies in detail the teaching-learning processes (Lijnse & Klaassen, 2004). Simultaneously and in interaction with the scenario LT-materials were constructed; scenario and LT-materials were finally tested in classroom practice. After data collection and analysis it was decided how the scenario and learning materials had to be adapted (see fig. 3). This procedure was repeated in the second research cycle.

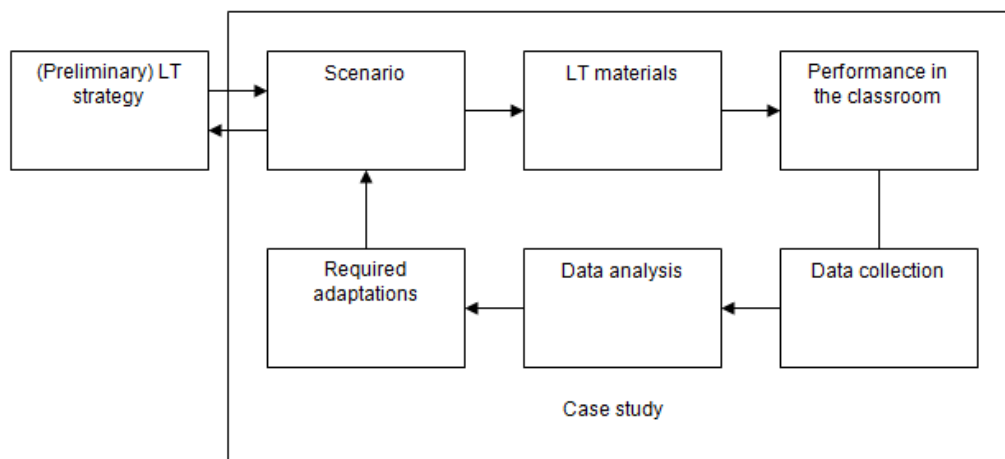


Figure 3: Design of a case study (after: Boersma, Knippel, & Waarlo, 2005)

In this sequence of design and research activities, the scenario fulfills a critical function. It consists of a detailed design of learning and teaching processes, accompanied by a set of argued expectations about the participants' behaviour and learning outcomes, and explains why it should operate according to the expectations.

LT-strategies and scenarios were developed both for general upper secondary (havo) education and for pre-university education (vwo). The difference between the two levels is in particular based on the selection of different social practices. The second practice at havo-level is about designing a welfare friendly pig stable, while the vwo-students have to research the overtraining syndrome.

#### Data collection and analysis

Table 2 summarizes some characteristics of the participating schools and students.

*Table 2: Characteristics of the schools involved in the case studies of the two successive versions of the design. (H = general upper secondary education (havo), V = pre-university education (vwo))*

	1 <sup>st</sup> research cycle		2 <sup>nd</sup> research cycle		
	School 1	School 2	School 3	School 2*)	School 4
Grade and level (number of students)	4H (23) 5V (16)	4H (24) 5V (23)	4H (25) 4V (23)	4H (27)	4V (20)
Age of students (years)	H: 15-16 V: 16-17	H: 15-16 V: 16-17	15-16	15-16	15-16
Number of teachers	2	1	2	1	1
Number of lessons	11	10	H: 12 V: 14	12	12
Time-period case study**)	Jan-Feb 2007	Feb-April 2007	April-May 2008	May-June 2008	Sept-Oct 2008

\*) School 2 participated in both research cycles, but with different group of students.

\*\*\*) Cases studies were executed subsequently. Within a research cycle, only minor and mainly textual adaptations of the scenario and learning materials were made.

Table 3 presents an overview of the data collection.

*Table 3: Overview of data collection*

Data source	Specification
Observations by the designer-researcher	In all lessons, written notes were made. Unexpected situations and remarkable statements of students and teacher were noted that (in)validated the expected activities in the scenario.
Audio recording of classes and groups	In all lessons, audio recorders and video cameras were placed in the classroom. In the case of group work, recorders were placed at the students' tables.
Workbook	In all lessons, the lesson materials consisted of a students' workbook.
List of concepts	Assignment included in the workbook in the second research cycle.
Concept maps	Assignment in the workbook in the second research cycle.
Written test	In the first research cycle.
Essay	In the second research cycle.
Evaluation form	Occurred after the execution of a case study, an evaluation form was filled in by students, containing questions about the motivation of students and valuation of the lesson series.
Reflections with teachers	After each lesson of the second research cycle. Finally, an evaluation interview was taken with all teachers after execution of the scenario.
Observation of a redesigned focus lesson with a small group of students	Between first and second research cycle, pretesting the focus lesson for the second version of the LT-strategy. Observations are used to fine-tune the focus lesson and the teachers' manual.

The hypothetical LT-strategy as described in the scenario guided the selection of data, the interpretation and analysis. Table 4 describes four possibilities that were distinguished in the analysis of the data, to decide for adaptation all LT-activities of the scenario.

Table 4: Adaptation of the LT-activities of the scenario that were considered when the scenario was compared with the performance in the classroom

	Scenario performed as intended	Scenario not performed as intended
Expected learning outcomes are attained	An adaptation of the scenario is not necessary	Additional information about the causes of the deviation is required before it can be decided if the scenario needs adaptation.
Expected learning outcomes are not attained	The scenario (and LT-strategy) should be adapted	Additional information is required about the causes of deviations and deficits; adaptation of the LT-strategy and scenario should be considered.

## 4. Results

### Outline of the LT-strategy

In the explorative phase, the outline of the LT-strategy was adopted from Westra (2008). It consists of three realistic contexts (practices, figure 4). A central steering question is evoked in the focus lesson (figure 4), and each context starts with the development of a steering question. A steering question is derived from the activity of a corresponding authentic practice. The first and second context are aiming at students' conceptual development of behavioural biology, whereby the concepts learned in the second context form an extension of the concepts from the first context. The third context aims to test students' knowledge of behavioural biology. Each context, including the focus lesson, is built up according to the problem posing approach. A reflection phase follows each LT-activity phase, wherein students reflect on the steering question of the context and the central steering question. After that, a new steering question is evoked, which makes it plausible to change to a new context.

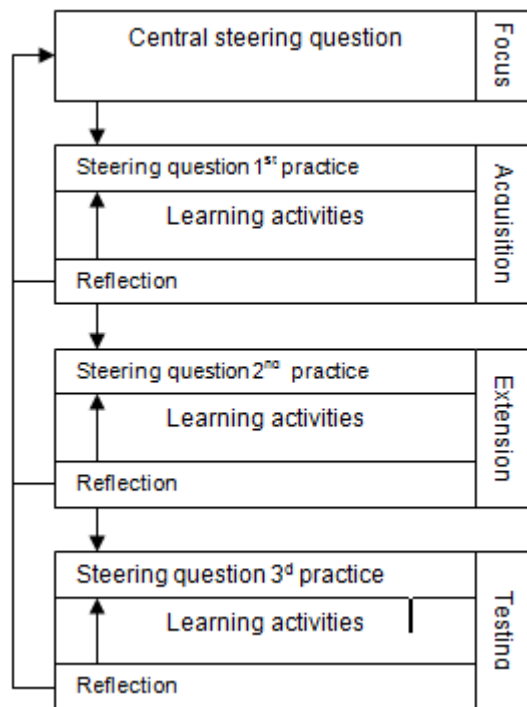


Figure 4: Outline of the LT-strategy (adapted from Westra, 2008)

Which social practices are suitable for learning and teaching behavioural biology? Social practices were selected on the base of the following five criteria. 1) Practices should meet the aims of behavioural biology. 2) Practices should emphasize several levels of biological organization. 3) Practices should elicit motives to increase students' motivation to learn. 4) It should be possible to reduce its complexity. 5) Authentic material of a practice should be available. Applying these criteria, the following social practices were selected (table 5).

Table 5: Selected social practices for havo and vwo

Phase	Havo	Vwo
Acquisition	Caring for your pet	
Extension	Designing a welfare friendly pig stable	Researching the overtraining syndrome of horses
Testing	Dealing with riots during football matches	

Each context has its own steering question, serving as a motive for exploring a new context. A major difficulty in designing a scenario with a non-interrupted storyline was that it seemed not always possible to develop a motive for exploring a new social practice, especially when further explanation was required and the question for explanation was not authentic in the practice the students were dealing with. To solve that difficulty some so-called 'embedded practices' were included. We defined an embedded practice as a (part of a) practice that is necessarily placed into the elaboration of another practice to create a non-interrupted storyline (Van Moolenbroek, 2012). For example, the stress mechanism (The General Adaptation Syndrome) is based on the scientific work of Selye (1978) and used in the first context ('how to care for your pet?') to explain the working of stress in dogs.

The design of the lesson series tested in the first research cycle was considered as a rapid prototype of the LT-strategy. An extensive comparison of the intended with executed scenario of the first version of the design revealed the following four deficiencies:

- A mistake in the design of the focus lesson, including an insufficient explication of the three perspectives on behaviour, resulted in a poorly developed central steering question.
- The needed lesson time did not coincide with the available lesson time.
- A lack of profoundness, particularly at vwo-level, which resulted in a decrease of students' motivation and a superficial conceptualisation of behavioural biology.
- Too few and short reflection phases in the scenario obstructed Recontextualising.

The above-mentioned deficiencies were identified as deficiencies in the scenario and the design of the lesson series. Therefore, four main improvements of the scenario and the design of the lesson series were made in the second research cycle. The focus lesson was renewed; the number of lessons was increased, the General Adaptation Syndrome was added for students of both educational levels, and reflection activities were incorporated more systematically, including the use of concept maps as a reflection tool. The outline of the elaboration of the LT-strategy in a lesson plan of the second research cycle is presented in Table 6.



Table 6: Outline of the lesson plan for learning and teaching behaviour of the second research cycle. (LTA = Learning and teaching activity)

Phase	Lesson	LTA	Description		
Focus	1.	1.1	Introduction of the subject by observing unexpected behaviour of a dog. Should serve for the development of a steering question and studying an article about behaviour of wolves that provides for the exploration of the three perspectives (function, causation, and development) on behaviour.		
		1.2			
		1.3			
1.4					
Acquisition	2.	2.1	Studying welfare of animals is homework and the 2 <sup>nd</sup> lesson starts with the focus on natural behaviour. The function of behaviour is elaborated in group and class discussion.		
		2.2			
		2.3			
	3.	3.1	What if natural behaviour cannot be performed? Studying causation of behaviour by looking at stress of dogs and the introduction of the General Adaptation Syndrome. The emphasis is on the normal reaction on stressors (acute stress).		
		3.2			
		3.3			
	4.	How to adapt to stressors? Studying adaptation to environmental factors. The development of behaviour is seen in the growing up from juvenile to adult and in the learning of special task for a dog.			
					4.1
					4.2
Phase	Lesson	LTA	Description		
			Havo	Vwo	
	5.	5.1	Reflection on the first practice by designing a concept map and introduction of the next practice: designing a welfare friendly stable.	Reflection on the first practice by designing a concept map and introduction of the next practice: researching the overtraining syndrome.	5.1
		5.2			5.2
	6.	6.1	Discussion of the welfare and stress of farm animals. A part of it is homework A part of it is homework for the next lesson. With the help of an embedded practice, the stress mechanism is studied. The emphasis on the stress reaction is now moved from acute to chronic stress.	After discussing the homework about overtraining in exercise, a behavioural research assignment is prepared by discussing the physiology of the stress mechanism (hormonal cycles). The emphasis on the stress reaction is now moved to chronic stress.	6.1
		6.2			6.2
Extension	7.	7.	Working in small groups on designing a welfare friendly stable	Discussion the homework about the stress mechanism and the General Adaption Syndrome Preparing the behavioural research assignment with the Novel Horse Test (NHT)	7.1
					7.2
	8.	8.	Working in small groups on designing a welfare friendly	Executing the NHT assignment in small groups	8

Table 6: Outline of the lesson plan for learning and teaching behaviour of the second research cycle. (LTA = Learning and teaching activity)

Phase	Lesson	LTA	Description	
			stable	
	9.		Presentations of the designs of the pig stable	Executing the NHT assignment in small groups
Test	10.	10.1 10.2	Reflection on the practice and introduction of the test practice about dealing with human aggression	
	11.	11.1 11.2	Constructing a concept map about aggression as preparation for writing the essay on the topic 'how to prevent riots' Executing the final assignment by watching video about riots	
	12.	12.	Executing the final assignment, writing the essay	

The data collected during the second research cycle show that the scenario is generally executed as intended. However, the data also show that the participating teachers (1) have some difficulties with the understanding of some of the behavioural concepts, (2) take too much time for explanation, and (3) regularly forget to evoke motives for learning. It was concluded that teachers were unfamiliar with the LT-strategy and lacked experience in teaching the concept-context approach and the problem posing approach. Consequently, the teachers' guidance can be improved by focusing more on the behavioural biology concepts and their coherence. Since much emphasis was given to the analysis of the concept maps in LT-activities, we will focus further on their analysis.

### Concept maps

It was recorded that adequate reflection time was programmed and that students' conceptual development was effectively stimulated by reflection through the construction of concept maps. In the havo-classes, the concept mapping assignment was too open and more guidance was needed. Vwo-students had difficulties in starting the design of the concept map and in deciding which concepts should be included. Both problems can be solved by adapting the instruction for students. No adaptation of the LT-strategy is required.

Both the technical quality and the domain-specific quality of students' concept maps were analysed, respectively, in order to determine whether the concept maps were constructed as intended, and to determine the students' conceptual development. Only 27% of the students' concept maps included linking phrases as a part of the propositions. Furthermore, it was observed that the concept maps showed a large variety in the number of propositions and structure. In general, it was concluded that the technical quality of the students' concept maps is weak, probably caused by a lack of experience in concept mapping by the teacher and the students. However, considering the domain-specific quality of the concept maps, it appeared that students were able to relate the concepts correctly. The concept maps showed a large diversity in the number of propositions and the individual student elaborated an average of 59% of the concepts included in the reference concept map, including all propositions that students had to acquire. Furthermore, the analysis showed that students have a satisfactory understanding of the behavioural biology concepts, in particular of the concepts stress and stress mechanism. For most behavioural concepts, the amount of correct propositions is as high as 80%.

From these findings, it was concluded that that students' conceptualisation could increase further when the technical quality of concept maps is improved.

In the third practice (see figure 4), concept mapping is used as a construction tool, preparing students for writing an essay about human aggressive behaviour.

Therefore, here the relationship between the domain-specific quality of the concept map and the essay was investigated.

The analysis showed that the quality of the constructed concept maps is determined by the use of behavioural biology concepts, perspectives, and the use of linking phrases. Furthermore, it showed that the better the domain-specific quality of the concept map, the better the quality of the essay students wrote from a behavioural biology viewpoint. Consequently, it was concluded that students could construct a high quality concept map when they understand the meaning of and relations between its concepts.

The analysis of the essays shows that the participating vwo-students used behavioural biology concepts adequately, while the participating havo-students argued from a practical viewpoint with a minimal use of behavioural biology concepts. Havo-students noted the causes of riots that they could find and formulate a solution. Vwo-students also used resources about aggression in addition to the given resources in the workbook, such as the Wikipedia encyclopaedia. These observations evoked the question if writing an essay is an adequate means for havo-students to recontextualise.

Finally, it was concluded that students' conceptual development results in an understanding of the behavioural biology concepts. Students did not always distinguish the different perspectives explicitly, but did correctly use the behavioural biology concepts. For example, students did not include causation, development, and function of behaviour in a concept map, but were able to use behavioural biology concepts in their essay. The LT-strategy for behavioural biology provides opportunities to recontextualise, although some improvements are desirable. A noticeable observation is that some students recontextualise, while others do not.

### **Conclusions**

The question whether students' awareness of behaviour is evoked by the LT-strategy can be answered positively. Students adequately conceptualized the behavioural biology concepts, and it was concluded that an adequate LT-strategy for behavioural biology could be constructed according to the concept-context approach and the problem posing approach. However, some adaptations to the final LT-strategy are proposed.

- The use of concept mapping as a reflection tool could be improved by a systematic construction of concept maps
- Students evaluated some texts in the workbook as too long. Therefore, length, level, and language in the final version of the texts in the workbook should be adapted.
- The sequence of the steering questions in the (second) practice of the building of a welfare friendly pig stable should be adapted in order to construct a more logical storyline.

Finally, it was concluded that the LT-strategy meets all design criteria, with the exception of the second design criterion indicating that an LT-strategy for behavioural biology should emphasize systems thinking. Systems thinking was only implicitly included. An explicit elaboration of systems thinking in which behaviour is understood as an emerging phenomenon would require a rethinking of the LT-strategy.

## **5. Reflection**

The PhD-study presented provides further empirical support for the concept-context approach. It shows that it is possible to design a feasible and effective LT-strategy based on a sequence of realistic contexts based on authentic social practices, and focussing on students' conceptual development.

The study contributes substantially to a design theory for context-based biology education. Analysis of the domain-specific LT-strategies of a number of completed design studies revealed that a small number of didactical structures are applied in different combinations in each of these studies (Boersma, 2011; Boersma & Waarlo, 2009). Two of these structures are characteristic for the concept-context approach: contextual transposition (i.e. educational adaptation of an authentic social practice to a realistic context) and recontextualising. A preliminary design theory for curriculum developers was constructed (Boersma, 2011), including the results of completed PhD studies and some studies in progress. In the LT-strategy for behavioural biology, three of the five of these didactical structures are integrated: the problem posing approach, contextual transposition and recontextualisation. The so-called yoyo-strategy (Knippels, 2002), focusing on sequencing levels of biological organization, was applied only implicitly.

In particular, the adaptation of the design of the focus lesson confirmed experiences from earlier studies that an adequate design is conditional for uninterrupted LT-processes and the attainability of the intended learning outcomes. Such findings also indicate, however, that an adequate design cannot guarantee that the intended learning outcomes are acquired. The ultimate success of a design theory is determined by how it is elaborated in a scenario and how teachers and students put it in practice.

### Key source

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## Adapting Authentic Science Practices into Contexts for Learning: The Case of Models and Modelling in Pre-University Chemistry Education

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# 30. Adapting authentic science practices into contexts for learning: The case of models and modelling in pre-university chemistry education

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## Abstract

*This research study explores the potential benefits of using authentic modelling practices as contexts for learning in chemistry education. An authentic modelling practice is characterized as professionals sharing common purposes, working to a similar type of modelling procedure, while applying relevant issue knowledge. The educational challenge is to adapt these practices to suit students' abilities and lead to desired learning outcomes. This study employs an educational design research approach for the construction of an intervention aimed at enhancing students' epistemological notions regarding models and modelling. The design knowledge is captured in design principles, a synthesis of strategy components and pedagogic effects underpinned by theoretical notions, empirical experiences and/or practical considerations. These design principles provide heuristic guidelines that support practitioners and educational designers in constructing authentic practice-based interventions for science education.*

## 1. Introduction

In this chapter we describe the adaptation of an authentic chemical modelling practice into a context for learning for use in pre-university chemistry education, students in grade 10/11 (age 16/17) in the Netherlands. The learning of models and modelling is regarded as an integral part of scientific literacy (Clement, 2000; Gilbert, 2004). However, many studies have revealed that students do not effectively learn about models and modelling (Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 1996). There is substantial evidence that the traditional chemistry curriculum does not fully support students' learning of models and modelling (Erduran & Duschl, 2004). A current belief is that - rather than teaching students about models constructed by others - students should become actively involved in modelling processes in which they develop understanding of their models including the evaluation and testing (Penner, Lehrer, & Schauble, 1998; Raghavan & Glaser, 1995). It has been claimed that this aspiration might be realized by designing a learning environment which accurately reflects an authentic science practice that employs models (Edelson, 1998; Roth, 1998; Sadler, 2007).

In broader perspective, making science learning more resemble authentic scientific practices has been a goal among educational reformers for several decades (Edelson, 1998). The potential benefits are that students become active learners acquiring scientific knowledge and developing skills and attitude in a meaningful context. Using authentic practices as contexts for learning in science education stems from and relates to the Activity theory in education rooted in sociocultural view on learning (Vygotsky, 1981; Leont'ev, 1978). Activity theory describes society in terms of connected social practices as manifestations of activity. The unit 'activity' is considered the foundation of knowledge. Activity theory considers the zone of proximal

development as a core concept, in which development involves cognitive, affective and volitional aspects.

An authentic modelling practice is characterised by professionals with common motives and purposes for model construction (feature I), working according a similar modelling procedure (feature II) and applying relevant knowledge (feature III) in the area they are working in. When using authentic practices as contexts for learning, one needs to acknowledge significant differences between the population of students and that of experts. An authentic practice-based curriculum unit needs to be designed such that it leads to desired learning outcomes within the constraints of the classroom (Lijnse, 1995). This study employs an educational design research approach, on the one hand to tackle the design challenges to achieve the benefits of authenticity in classroom, on the other hand to generalize the scientific yield in empirically validated design principles. Design principles are defined as tools providing heuristic guidelines for strategy components for realising pedagogic effects in classroom (Van den Akker, Gravemeijer, McKenny, & Nieveen, 2006). Design principles inform practitioners and educational designers about the construction of interventions. The central research question addressed is:

*What are the characteristics of a teaching-learning process using an authentic modelling practice as context for learning in pre-university chemistry education?*

In the following we will first clarify the design stages, the respective quality criteria and evaluation methods used in this study. Secondly, we describe the analysis and selection of suitable authentic modelling practices for use as context for learning. Thirdly, we describe the construction phase consisting of iterative stages of development of the intervention, empirical testing and evaluation thereof. Finally, we describe the outcomes in terms of design principles, a synthesis of strategy components and intended pedagogic effects underpinned by theoretical notions, empirical experiences and/or practical considerations. We end this paper with a reflection on the use of authentic practices as context for learning in chemistry (or science) education.

## **2. Overview of development stages and their quality criteria**

In Table 1 an overview is presented of the consecutive development stages, respective quality criteria and evaluation methods employed in this Educational Design Research (EDR) study, building on earlier research (Nieveen, 1999, 2009). The relevance (content validity) concerns the need for the intervention based on 1) a literature analysis of the students' learning difficulties related to models and modelling, 2) strategies described in literature to overcome the reported learning difficulties, and 3) a complete and detailed description of the authentic modelling practice to be used as context for learning. The consistency (construct validity) concerns the design of the intervention, e.g. the embedding of the essential elements of the authentic modelling practice in the intervention and the construction of a meaningful sequence of teaching and learning activities. The practicality denotes the feasibility of the intervention in the settings for which it has been designed and developed, on the level of 'expected', e.g. argued predictions about the functioning of the intervention, and 'actual', e.g. empirical data on the realised enactment of the intervention. The effectiveness is focused on students' learning outcomes, also both on the level of 'expected' and 'actual'.

Table 1: Overview of consecutive design stages, respective quality criteria and evaluation methods in this EDR study

Design stages		Analysis of authentic modelling practices		Development and empirical testing of the intervention		
		Design specifications	Outline of the design	Partly detailed intervention	Complete intervention	Implemented intervention
Relevance		<ul style="list-style-type: none"> <li>• Document and literature analysis</li> <li>• Expert appraisal</li> </ul>	<ul style="list-style-type: none"> <li>• Screening</li> </ul>			
Consistency			<ul style="list-style-type: none"> <li>• Screening</li> <li>• Expert appraisal</li> </ul>	<ul style="list-style-type: none"> <li>• Screening</li> </ul>	<ul style="list-style-type: none"> <li>• Screening</li> <li>• Expert appraisal</li> </ul>	
Practicality	expected		<ul style="list-style-type: none"> <li>• Screening</li> </ul>	<ul style="list-style-type: none"> <li>• Screening</li> <li>• Walkthrough</li> </ul>	<ul style="list-style-type: none"> <li>• Expert appraisal</li> </ul>	
	actual			<ul style="list-style-type: none"> <li>• Micro-evaluation</li> </ul>	<ul style="list-style-type: none"> <li>• Try-out</li> </ul>	
Effectiveness	expected		<ul style="list-style-type: none"> <li>• Screening</li> </ul>			<ul style="list-style-type: none"> <li>• Expert appraisal</li> </ul>
	actual					<ul style="list-style-type: none"> <li>• Case study</li> </ul>

In each design stage a prototype of the intervention is evaluated with use of appropriate formative evaluation methods that fits the evolutionary stage. The first design stage started with a literature search to reveal students' learning difficulties related to models and modelling, as well as to gain an overview of proposed teaching strategies to overcome the reported learning difficulties. In addition, authentic modelling practices were searched for, analysed and selected, based on thorough elaboration of the practices (document analysis) and a series of interviews with representative experts (expert appraisal). The findings informed the design specifications and provided input for the second design stage: the outline of the design. The outline described the selected modelling issue for students to work on, embedded in the selected practice, and the planned sequence of teaching and learning activities. The outline was screened by members of the design team. The screening focussed on identifying critical components and activities in the practice to incorporate in the educational design in order to maintain coherency and authenticity from students' perspective. In addition, the screening was focussed on identification of the expected practical feasibility in classroom and expected students' learning outcomes. Finally, subject matter experts were consulted in order to validate the scientific soundness of the outline of the design.

In the third design stage, partly designed intervention, students' initial involvement in the selected practice was investigated. The aim was to validate whether the selected authentic modelling practice was in line with students' competences, pre-existing knowledge base and did induce interest and motivation to study the practice in more detail. The first set of teaching and learning activities have been designed and enacted by a small group of students. The partly designed intervention has been screened by the members of the design team preceding enactment. The screening focussed on the content and expected outcomes of the respective teaching and learning activities. In addition, before enactment the set-up of the partly designed intervention has been discussed in detail by the researcher and the teacher to make explicit the underlying rationale and the expected outcomes (walkthrough). Finally, the partly designed intervention has been enacted by a group of students outside classroom (micro-evaluation).

The students were observed and interviewed in order to gain insight in their involvement and perceived level of difficulty of the modelling issue at hand.

In the fourth stage the complete intervention was constructed iteratively. The fourth stage consisted of two research cycles, respectively in two classes in two different schools with an evaluation and revision in between. The construction of the complete intervention was conducted in close cooperation with the teachers (expert appraisal), who were also committed to enact the intervention in their own classes. Teachers' tacit knowledge and expertise, i.e. their implicit or unarticulated knowledge learned and transmitted through experience and apprenticeships, was incorporated in the design in order to reduce discrepancies between curriculum design and actual classroom environments as much as possible (Kensing & Blomberg, 1998; Könings, Brand-Gruwel & Van Merriënboer, 2005; Könings, Zundert, Brand-Gruwel & van Merriënboer, 2007; Mankin, Cohen, & Bikson, 1997). The pedagogical decisions were described in design principles (McKenney, Nieveen, & Van den Akker, 2006). The try-out concentrated on the perceived meaningfulness by students, e.g. students' knowing *why what* to do at every step in the teaching-learning process. During the design process and in between the research cycles the complete intervention was screened by members of the design team. The focus was to evaluate the sequence of teaching and learning activities from students' perspective.

The last and fifth stage the students' learning outcomes related to models and modelling was tested in a case study in one class at one school. The case study was focused on students' gained insight in advanced model features purpose, goodness of fit, reliability and validity, as well as insight in the applied modelling procedure.

### 3. Analysis of authentic modelling practices

In our society many chemistry-related authentic practices are available. For example, practices aiming at quality evaluation of products, e.g. drinking water, food or consumer products for personal health, or practices with an emphasis on research, e.g. developing new catalysts or acquiring fundamental understanding of structure-property relations of proteins. Within such practices the specific attitudes, characteristic procedures and issue knowledge play an obvious role. The relevance of the skills and issue knowledge involved is not questioned, since the participants of such a practice have clear motives to use and extend these accordingly.

However, regarding the use of authentic modelling practices as contexts for learning, it should be noted that it 'cannot be expected that students are able to conceptualize the goals and direction to follow with the same width and depth as the professionals (Westbroek et al., 2009). Therefore, the suitability of authentic modelling practices for use as contexts for learning needs to be justified from educational points of view and students' perspectives.

#### Method

In four consecutive steps authentic modelling practices were searched, analyzed and selected based on the on the following aspects (Prins, 2008):

- a. Students' interest: to what extend are students interested in and motivated for the modelling issue at hand;
- b. Students' ownership: to what extend can students develop ownership and personal autonomy with a certain modelling issue;
- c. Modelling procedure: to what extend are the main stages in the modelling procedure in the authentic practice in line with students' common sense notions;

- d. Complexity: to what extent are students able to deal with the complexity of the modelling issue at hand, e.g. the number of factors and parameters involved;
- e. Familiarity: to what extent are students familiar with the modelling issue at hand, e.g. which concepts and skills are already mastered by students and which are not.

As a first step, a list of authentic chemical practices, in which models were used as a predictive tool, was generated by internet search. The search was conducted in January 2004 with search machine Google using a combination of the keywords 'modelling', 'procedure', 'predictive', 'chemistry' and 'practices'. The rationale for using this open search method was to acquire a broad range of authentic chemical modelling practices, including social, technological and research practices. Given concerns about the reliability of some internet resources, the validity of this search method was ensured by selecting only references to well established institutes, e.g. companies or governmental authorities. Solely Dutch websites were included in our search, since Dutch practices were expected to be more recognisable for Dutch students.

Secondly, each practice was reviewed according to a subset of the aspects, e.g., students' interest (a), complexity of the issue (d), familiarity with the issue (e) and a conditional aspect related to the feasibility of performing laboratory work in classroom. This review process was conducted independently by two researchers. Both researchers compared and discussed their valuations on each aspect resulting in a final judgment of practices to be analyzed in the third step.

Thirdly, the selected practices were analyzed in depth to reveal the motives for model development, the modelling procedure and the issue knowledge involved, using relevant documents (reports, articles) and by expert-interviews. The interview data were analyzed from an interpretative perspective by two researchers independently (Smith, 1995). The focus was on the expert's statements concerning the motives and purposes for model construction (feature I), the expert's reflections on the characteristic modelling procedure (feature II) and the relevant issue knowledge involved (feature III).

Fourthly, the results of the in-depth analysis of the authentic chemical modelling practices were evaluated according to all aspects, e.g. students' interest (a), students' ownership (b), modelling procedure (c), complexity (d) and familiarity (e). This assessment process was conducted independently by two researchers as described in step 2.

## **Results**

The internet search resulted in two practices valued as suitable for educational purposes: (1) modelling human exposure and uptake of chemicals from consumer products, and (2) modelling drinking water treatment. The latter practice was adapted into a context for learning and tested in classroom, primarily because of the availability, or relative easy development, of laboratory experiments related to water treatment. Below the major characteristics of the practice 'modelling drinking water treatment' are described. More details can be found in Prins, Bulte, Van Driel and Pilot (2008).

### ***Design specifications***

The authentic practice of modelling drinking water treatment is that of the chemical process engineers involved in the process of drinking water treatment in order to improve efficiency and minimize costs. The objective of this authentic practice is to identify and describe quantitative relations between the input and output concentration of undesired constituents depending on

relevant process variables. Such quantitative relations can be used to predict the quality of the drinking water after treatment as a function of the quality of the incoming (raw) water and the execution of the treatment process itself.

To develop such quantitative relations a characteristic modelling procedure is applied by modelling experts (Prins, Bulte, & Pilot, 2011). In broad outline, three distinctive stages can be distinguished, each evoking the application of specific scientific (biological, chemical and/or physical) and mathematical knowledge. The first stage involves the studying of the principles underlying the mechanisms of the treatment step in order to identify relevant process variables. This stage might include an orientation on process models already available and described in the literature. The second stage involves the gathering of experimental data under controlled conditions, both at the laboratory (pilot) scale and in real industrial plants. The third stage involves the development of a process model that describes the quantitative relations between input, output and relevant process variables. The modelling of the drinking water treatment is conceptualised in Figure 1. The block arrows indicate the flow of water with contaminants to be removed in treatment *step N*.  $C_{iN,in}$  denotes the incoming amount of contaminant *i*, while  $C_{iN,out}$  denotes the residual amount of contaminant *i* after *step N*. The removal efficiency in each step is affected by process variables, symbolised by  $pV_N$ .

In the authentic practice of modelling drinking water treatment, basically two modelling approaches are applied, namely the empirical and the mechanistic approaches. The mechanistic approach starts from a well-defined theoretical knowledge base, whereas the empirical approach aims to describe process behavior by fitting mathematical models to a set of experimental data. From a scientific (technological) point of view the mechanistic approach is preferred, since it strives to understand and describe mathematically the mechanics underlying the processes occurring in a given system. However, in many cases the underpinning theoretical knowledge is lacking, thus favoring an empirical approach.

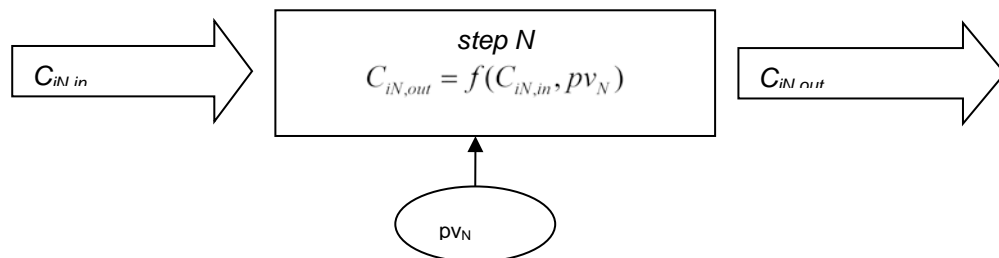


Figure 1: Conceptualised scheme of the modelling of the process of drinking water treatment. The block arrows indicate the incoming water stream, containing contaminants ( $C_{iN, in}$ ) to be removed, and the outflowing water stream, with a residual concentration of contaminants ( $C_{iN, out}$ ). The quantitative relation between output, input and process variables can be formalised by a formula  $C_{iN, out} = f(C_{iN, in}, pV_N)$ .

### Outline of the design

The modelling of the complete drinking water treatment process comprises numerous steps, parameters and process variables. It was decided to 'zoom in' on the process of turbidity removal by coagulation/flocculation, based on valuations regarding students' (cognitive) abilities (e.g. involved chemical and mathematical knowledge and students' pre-existing knowledge

base) and affective aspects (e.g. students' interests and sense of ownership). The major characteristics of the adapted authentic practice as context for learning are portrayed below.

Turbidity is caused by small particles, such as colloids and fine silt. During coagulation/flocculation treatment these particles are removed by adding a coagulant, such as ferric chloride. The efficiency of turbidity removal is affected by chemical process variables, such as the turbidity of the incoming water ( $turbidity_{in}$ ), temperature ( $T$ ), total salt concentration ( $c[salt]$ ), acidity ( $pH$ ) and the dose coagulant ferric chloride ( $V$ ). In addition, several process conditions affect the efficiency of turbidity removal, such as the stirring method, frequency and duration. The dose coagulant ( $V$ ) and process conditions can be directly manipulated. The coagulation/flocculation treatment is conceptualized as an input-output system, as depicted in Figure 2.

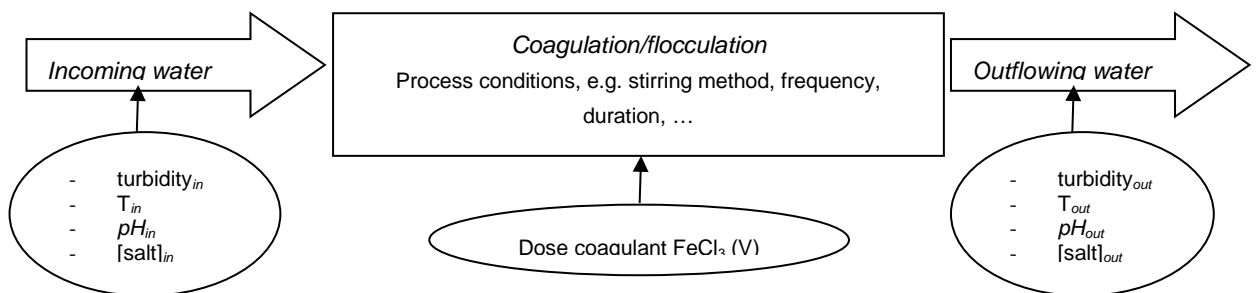


Figure 2: Conceptualised scheme of the coagulation/flocculation treatment process including relevant process variables. The block arrows indicate the flow of water.

The aim of modelling is to gain understanding how the various process variables influence the  $turbidity_{out}$ . The influence of the relevant chemical process variables is described by a regression model, such as  $turbidity_{out} = f(turbidity_{in}, V, T, pH, [salt])$ . The model is evaluated on epistemic values, such as purpose, goodness of fit, reliability and validity. The applied modelling approach can be typified as empirical (or black box, data-driven). The applied modelling process in the authentic practice consists of three distinct stages as depicted in Table 2.

Table 2: Overview of the modelling stages and accompanying situated knowledge in modelling turbidity removal by coagulation/flocculation

Modelling stages	Situated knowledge
Study the working of the treatment step	Coagulation/flocculation Process variables
Gather empirical data	Experiments under controlled conditions Correlation & regression
Develop a process model	Multiple regression

#### 4. Development and empirical testing of the intervention

After having decided on the design specifications and the outline of the design, the challenge was to construct a complete intervention to achieve the benefits of authenticity. The development of the intervention was guided by a design framework as depicted in Table 3, building on the 5E Learning Cycle (Trowbridge, Bybee, & Powell, 2000) rooted in inquiry-based learning and the 'instructional version of an authentic practice' (Bulte, Westbroek, De Jong, & Pilot, 2006).

Table 3: Design framework for the construction of an intervention using an authentic practice as a context for learning, based on the 5E Learning Cycle and the instructional version of an authentic practice

5E Learning Cycle	Design strategy / Instructional functions
ENGAGE/orientate on the practice	Activities <i>elicit curiosity, interest and involvement</i> . Students are introduced to the practice at hand, e.g. its aims and societal embedding, and become motivated to study a particular problem posed in the practice. Students make connections with prior conceptual and procedural knowledge base and think about what they will learn during upcoming activities.
EXPLORE/zoom in on an exemplary problem	Activities <i>create a demand for knowledge</i> to solve the exemplary problem successfully. Students develop ownership of the exemplary problem and think of a route to solve the problem. Students become aware of the type of activities to conduct and the conceptual knowledge to learn.
EXPLAIN/solve the exemplary problem	Activities <i>guide learners to identify and improve upon mastered concepts, processes and skills, and to learn new competencies</i> . Students study articles and documents related to the exemplary problem, conduct hand-on lab activities to explore hypothesized relations between variables, analyze data with use of appropriate techniques and develop a (mathematical) model, until a satisfactory solution for the exemplary problem can be presented.
EVALUATE/reflect on the findings	Activities that allow learners to retrospectively <i>reflect and evaluate</i> upon the presented solution, e.g. a (mathematical) model, and their newly gained conceptual and procedural knowledge.
ELABORATE/express the findings	Activities provide learners with an opportunity to <i>express and communicate</i> what they have learned and to figure out what it means. Students share ideas with each other and with their teachers. Students draw up a project plan for solving a similar problem posed in the practice, to experience the broader applicability of the gained knowledge.

The design framework was also inspired by research on meaningful teaching-learning processes (Cobb, Stephan, McClain, & Gravemeijer, 2001; Kortland, 2001; Lijnse & Klaassen, 2004; Westbroek, 2005).

From the perspective of the intervention, the design framework in Table 3 articulates the requirements that a set of learning activities must meet to achieve the particular learning objectives. However, decisions regarding what science content to teach and tasks and materials that will help students make desired meaning are interrelated and should be thoughtfully made



in light of desired goals for students and how students learn. Inspired by McKenney, Nieveen and Van den Akker (2006), we captured and described the major pedagogic decisions as design principles. Design principles are prescriptive in nature and focus on creating learning environments and products rather than describing how learners acquire knowledge and skills from these environments or products (Merrill, 2002). Design principles, in our interpretation, consist of strategy components that give rise to pedagogic effects, underpinned by theoretical notions, empirical experiences and/or practical considerations. Figure 3 depicts a conceptualized scheme of a design principle.

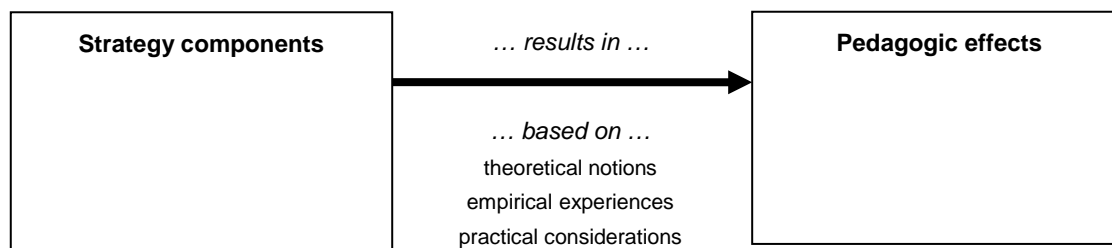


Figure 3: A design principle linking strategy components and pedagogic effects, underpinned by theoretical notions, empirical experiences and/or practical considerations

In this study the pedagogic decisions were categorised in three design principles, namely motives & purposes, models & modelling and chain of activities. The design principle of *motives & purposes* deals with involving learners in a focal event embedded in its cultural setting (Gilbert, 2006). This implies that the setting, the behavioural environment, the specific language and the extra-situational background knowledge are such that students become engaged in a modelling activity. The design principle of *models & modelling* deals with focusing learners on the essential generic content regarding models and modelling. The design principle of *chain of activities* deals with constructing a sequence of teaching-learning activities such that learners constantly know *why what* to do at every step in the process.

### Method

The development of the intervention comprised three consecutive stages. In the stage partly designed intervention, the students' engagement in the practice and their prior knowledge base regarding the modelling issue at hand were investigated. In the stage complete intervention, the practicality of the designed intervention was empirically tested in two research cycles, with focus on students' experienced meaningfulness. In the stage implemented intervention, the intervention was investigated on the effectiveness, with focus on the students' learning outcomes related to models and modelling. Below, the research aims and applied formative evaluation methods in each stage are described.

#### **Partly detailed intervention**

In this stage we focused specifically on the students' initial engagement in modelling drinking water treatment. The modelling of drinking water treatment should appeal to students, evoke their interest and ownership, encourage autonomy and willingness to work and build on pre-knowledge and intuitive notions. The students' involvement should be initiated at the start of the intervention. Therefore, learning tasks were designed which were enacted by a group of students (Prins, et al., 2009). The learning tasks were thoroughly screened by the members of the design team in light of the complete intervention. The group consisted of 18 students, grade 10/11 (age 16-17) from three different schools in the city of Utrecht, the Netherlands. All

students took chemistry classes at pre-university level. The students worked in groups of three persons. The enactment took place outside of the regular class situation. The teacher was member of the design team and well informed in the underlying pedagogy. In the first three learning tasks, students orientate themselves on the practice. In the fourth and last task, student teams were given the open task to draw up a plan of action to solve the exemplary problem of modelling the removal of water turbidity themselves. In this plan of action students express a series of modelling activities. The teacher did give help, feedback and coaching if needed. At the end each student team delivered a plan of action describing a modelling procedure to come to a solution for the modelling issue at hand. In addition, an evaluative group discussion was held in which students reflected on affective and cognitive aspects.

All plans of actions were analysed by two researchers independently to identify the different modelling stages and to judge the quality thereof. Preceding the analysis, both researchers developed and agreed upon a reference modelling procedure as evaluative framework. A rater consistency check was conducted by calculating the intraclass correlation coefficient using a two-way mixed effects model (Shrout & Fleiss, 1979). The group discussions were analysed from an interpretative perspective (Smith, 1995). Students' statements were coded according to criteria students' interest and ownership or familiarity and complexity. The inter coder agreement was tested for by calculating the percentage of statements coded equally by both researchers. We used 80 per cent as lower limit for a substantial level of agreement (Miles & Huberman, 1994).

### ***Complete intervention***

In this stage the complete intervention was designed and tested in the educational context it was designed for, e.g., students grades 10/11 (age 16–17), pre-university chemistry education. The design of the intervention was accompanied by a set of argued expectations of how the teaching-learning process is expected to take place and why it should operate according to the expectations (Lijnse, 1995). The method strongly resembles what Cobb, Confrey, DiSessa, Lehrer and Schauble (2003) described as 'design experiments' conducted in the classroom.

The intervention was tested in two research cycles, in four classes in two different schools in the period from 2008 till 2009. Between each enactment the realized teaching-learning process was evaluated, reflecting upon and adjusted. The complete intervention comprised eight lessons of 50 minutes, excluding time for self-study. The students were grouped into teams of four persons. The teachers were well acquainted with the content and pedagogy of the curriculum unit, since they were involved in the design. The evaluation focused on the practicality of the intervention. In particular, we focussed on the experienced meaningfulness from students' perspectives, e.g. why what to do at every step in the process.

The collected data sources were audio-taped conversations of student teams at work and written answers of student teams. Field notes were made to determine whether the teaching-learning processes were enacted in class as intended. The audio-taped conversations of the student teams at work were used as primary sources. The written answers were used to check the trends noticed. The conversations of the student teams at work were transcribed *verbatim* and coded from an interpretative perspective (Smith, 1995) by two researchers independently. The realized students' notions and attitudes were compared with those expected. A rater consistency check was conducted by calculating the intraclass correlation coefficient using a two-way mixed effects model (Shrout & Fleiss, 1979). In addition, every student filled in a written questionnaire individually after each lesson. The major purpose of the written questionnaire was

to reveal students' valuations of the designed teaching-learning activities and to check to what extent students have a perspective and understanding of future activities to conduct to solve the exemplary problem. Finally, the findings and results were discussed by the whole research team to identify underlying considerations and to unravel students' perspectives.

### ***Implemented intervention***

In this stage the focus was on revealing the actual effectiveness of the intervention in classroom regarding students' learning outcomes related to models & modelling, e.g. the epistemic notions regarding models (purpose, goodness of fit, validity, reliability) and the process of modelling (pros and cons of a data-driven, empirical modelling approach). The intervention was tested in a small-scale case study, with a classroom and its teacher as the unit of analysis (Cobb, Stephan, McClain, & Gravemeijer, 2001). The data collection and analysis were concentrated around teaching-learning activities that embody the learning of epistemology of models and modelling. The collected data sources were audio-taped conversations of the student teams at work, written answers of the student teams, interviews with the student teams and field notes. The audio taped conversations and written answers were analyzed by two researchers independently. A rater consistency check was conducted by calculating the intraclass correlation coefficient using a two-way mixed effects model (Shrout and Fleiss, 1979).

### **Results**

For sake of clarity we highlight the major findings and main conclusions. More details can be found in Prins, Bulte, Van Driel and Pilot (2009), Prins (2010) and Prins, Bulte and Pilot (2011).

### ***Partly detailed intervention***

Two major trends were identified within students' interest: 'appreciation of the clear link between chemical theory and practice' and 'the understanding of models and learning to construct models'. A major trend within ownership was that the issue encouraged students to think 'creatively about experiments'. The group discussion revealed that a majority of the students experienced the unit as interesting. Students especially appraised the high level of authenticity.

The results showed that students were familiar with the chemical concepts involved. As for the students' modelling approach, the findings suggest that the students were well able to articulate a modelling procedure in rudimentary sense. However, as it comes to the particular mathematical models employed, the results showed a more dispersed picture. Students were rather unfamiliar with the syntax of the formulas, the construction method and the empirical basis of the models.

In short, it was concluded that the practice of modelling drinking water treatment complied with student' interest and ownership in sufficient way. In addition, the issue of clearance of water turbidity by coagulation & flocculation showed to be in line with students' intuitive modelling notions.

### ***Complete intervention***

This stage aimed at designing an intervention which functioned in classroom according expectations. The practicality of the designed intervention was measured according to students' perceived meaningfulness, taken as students' being aware about why what to do at every step in the teaching-learning process. The structure of the final intervention, in terms of the development of situated knowledge and modelling skills coupled by content related motives

(Lijnse & Klaassen, 2004), is depicted in Figure 4. This final version was appreciated by students and teachers for the logical sequence, meaning and feasibility of the learning activities.

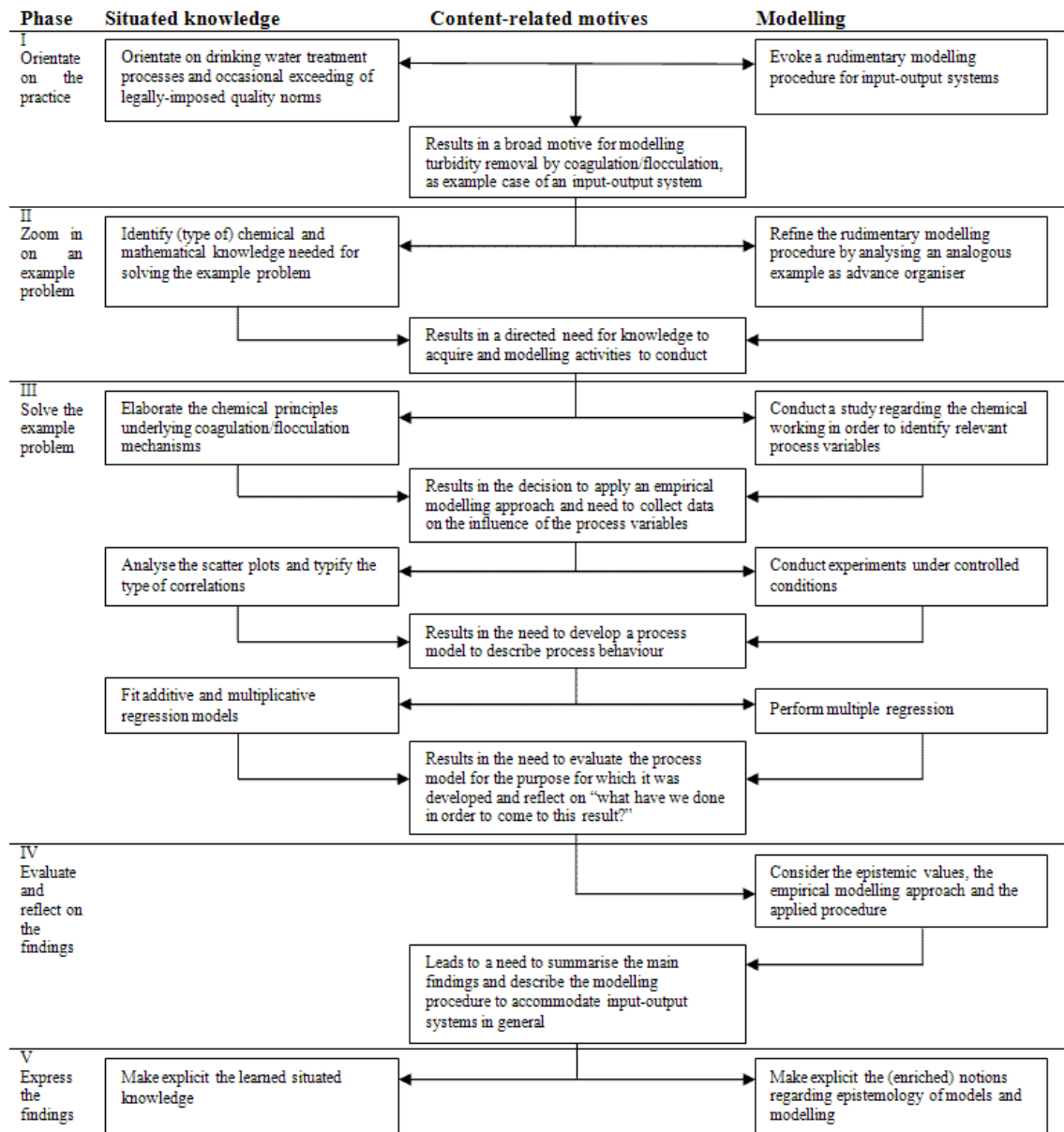


Figure 4: A structure of the teaching-learning process using the authentic practice 'Modelling drinking water treatment' as a context for learning. The boxes represent major stages in the teaching-learning process. The arrows indicate the flow of the process.

#### Implemented intervention

The designed intervention proved to foster students' insight into the epistemic values purpose, goodness of fit, reliability and validity (Prins, 2011). Students learned to describe and formalise the process behavior in mathematical models. In this respect, the modelling process resembles what Gravemeijer (1999) typified as emergent modelling: 'a process of gradual growth in which formal mathematics comes to the fore as a natural extension of the student's experiential

reality'. Students developed competencies to reason in a formal way about modelling. In addition, students showed to be able to discuss the pros and cons of the applied empirical modelling approach. The majority of the students put forward relevant notions, e.g., the absence of a sound theoretical foundation and the need for a good data set (number and accuracy) to describe the process behaviour. However, only a minority of the students reflected upon the broader applicability of the learned empirical modelling approach for other input-output modelling issues.

## 5. Yield of this study

In this section we describe the emerged design principles underlying the design intervention, using the construct presented in Figure 3. The empirically validated design principles are grounded in the results from the classroom enactments. More information about the connection between the empirical results and the generalized design principles can be found in Prins (2010) and Prins, Bulte and Pilot (2011).

The design principle of *motives & purposes* deals with involving learners in a focal event embedded in its cultural setting (Gilbert, 2006). The design principle provides a couple of strategy components which focus on students' involvement, relevant situated knowledge and proper assessment. The design principle is shown in Figure 5.

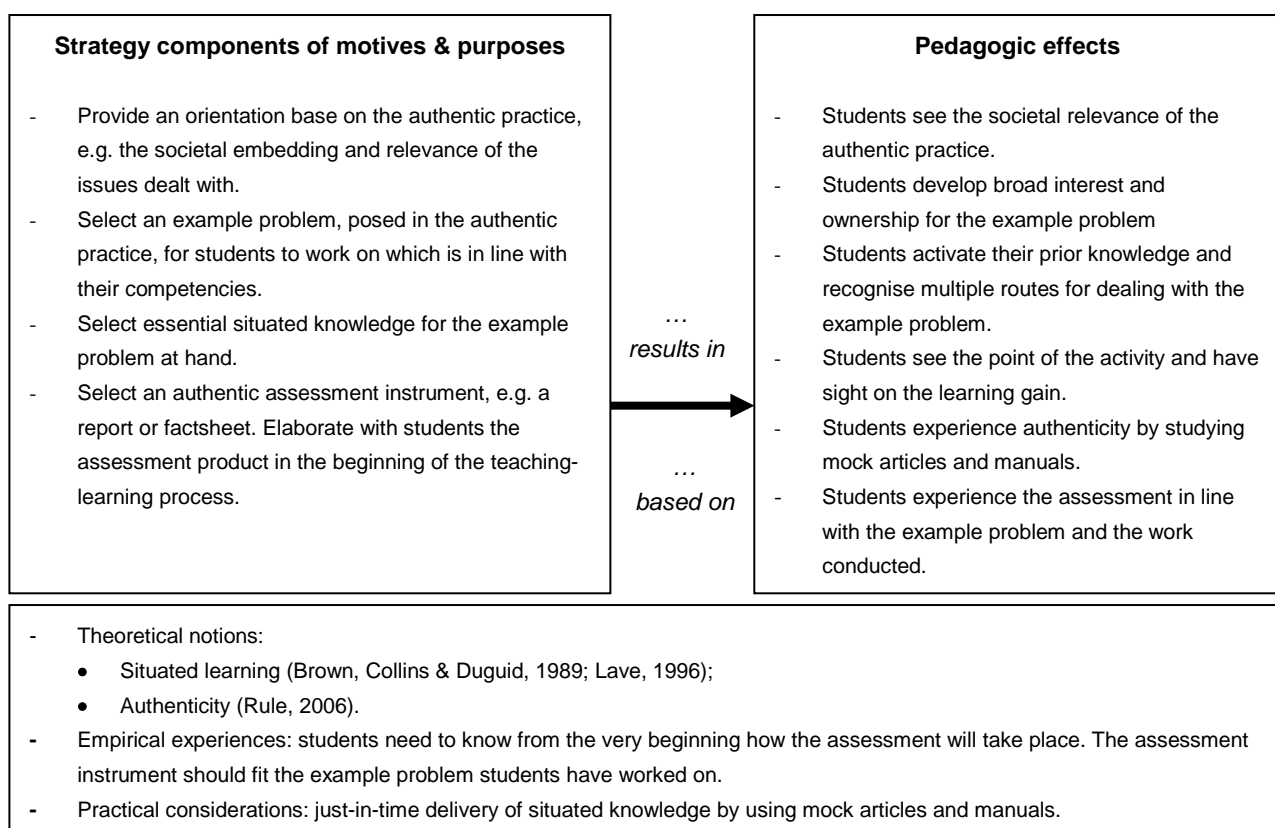


Figure 5: Conceptualised scheme of the design principle 'motives & purposes'

The design principle of models & modelling deals with focusing learners on the essential generic content regarding models and modelling. In present case the epistemology of models, e.g. purpose, goodness of fit, reliability and validity, and of the process of modelling, e.g. the pros and cons of the empirical modelling approach. The design principle is shown in Figure 6.

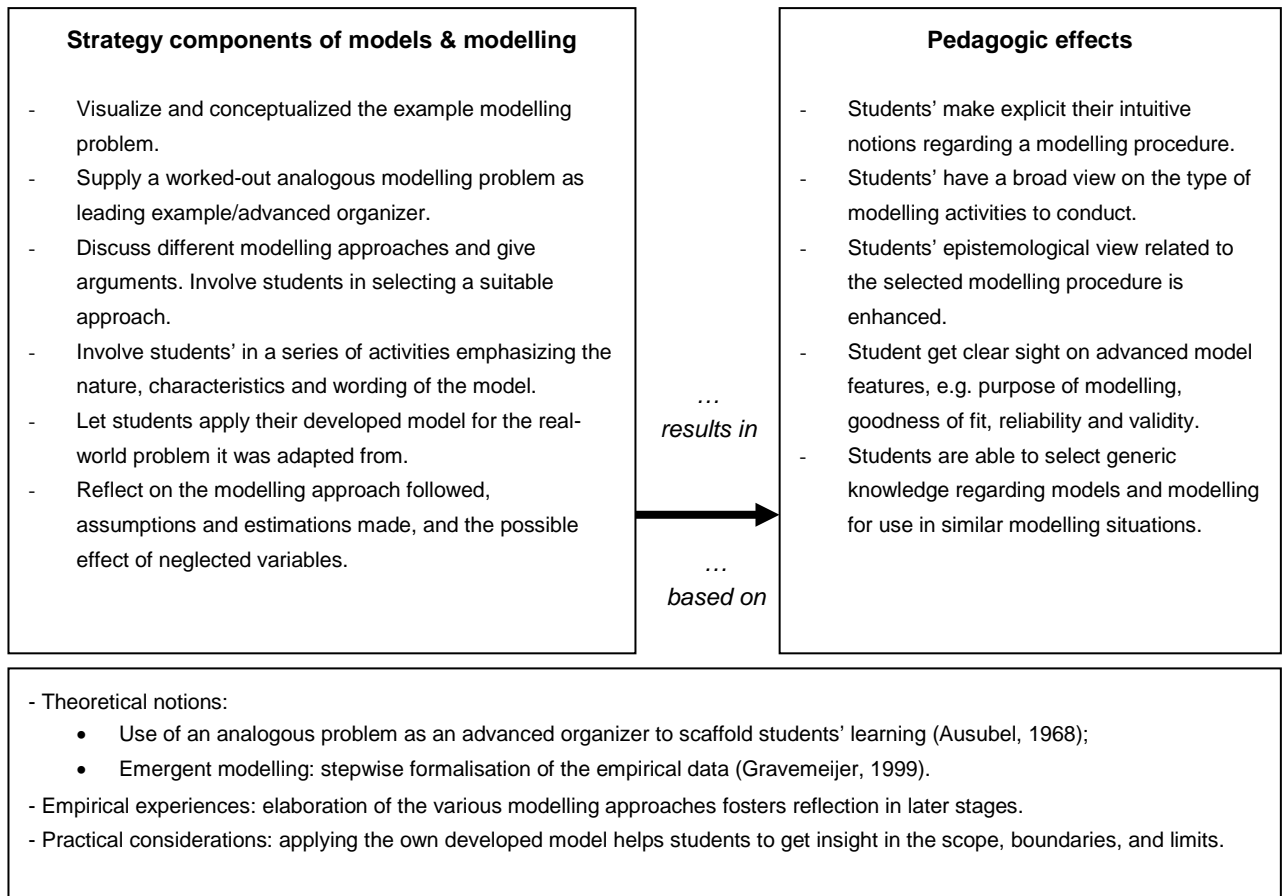


Figure 6: Conceptualised scheme of the design principle 'models & modelling'

The design principle of *chain of activities* deals with constructing a sequence of teaching-learning activities such that learners constantly know *why what* to do at every step in the process. The findings showed that students, in general, experienced the sequence of teaching-learning activities as meaningful. The design principle is shown in Figure 7.

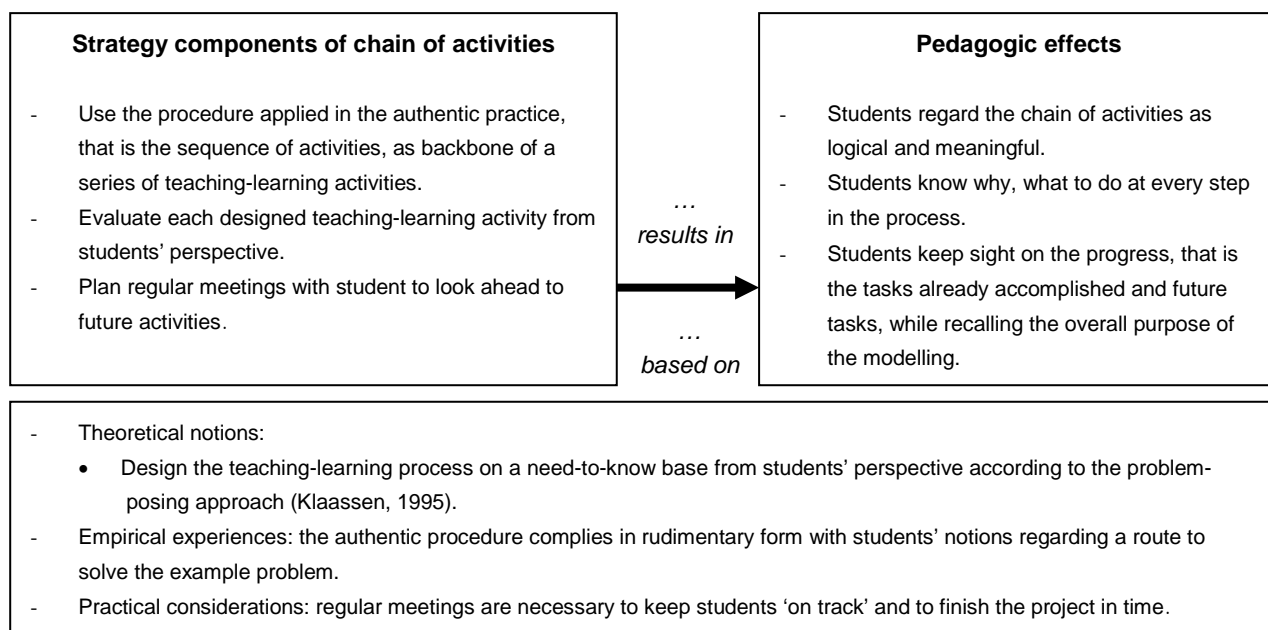


Figure 7: Conceptualised scheme of the design principle 'chain of activities'

## 6. Reflections on the use of authentic practices as contexts for learning

This research study supports the claim that learning environments that actually reflect real science practices fosters students' motivation, involvement and ownership and enables them to acquire knowledge in meaningful contexts (Edelson, 1998). However, an authentic practice needs to comply with a number of prerequisites to be suitable for use in pre-university chemistry (science) education:

- The objectives in the adapted authentic practice should match the learning goals of pre-university education;
- The example problem(s) should be shaped and conceptualised such that it (they) become(s) recognisable for students;
- An existing well defined procedure, in line with students' intuitive notions, should be available from which a sequence of teaching-learning activities can be derived;
- The situated chemistry (science) knowledge involved should be in line with students' (cognitive) abilities;
- Possible laboratory work, use of advanced computer tools, etc. should be practically feasible in the classroom.

The process of adaptation of an authentic practice into a context for learning is characterised by shifts of emphasis, applying simplifications, selecting and presenting chemistry (science) knowledge and paying attention to students' motives, attitudes etc. The main objective in the process of adaptation is to maintain the coherency within the constraints of the classroom. The heuristic value of the emerged design principles are limited within the following conditions:

- Pre-university chemistry education;
- Students grade 10-11 (age 16/17);
- Domain: models and modelling;
- Authentic modelling practices as contexts for learning.

In conclusion, the use of authentic practices as contexts for learning offers a valuable source of inspiration for designing teaching-learning processes and, if properly adapted, does lead to the intended learning outcomes. However, this conclusion is based on the adaptation of (only) one well defined authentic practice established after a thorough and prolonged design process. The teachers were given time to become acquainted with the underlying pedagogy and practical feasibility in the classroom. Future research is needed to contribute to and make explicit the design knowledge regarding the construction of authentic practice based curriculum materials.

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## An Approach for Design-based Research Focusing on Design Principles for Science Education: A Case Study on a Relevant Context for Macro-micro Thinking

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# 31. An approach for design-based research focusing on design principles for science education: A case study on a relevant context for macro-micro thinking

Marijn Meijer, Astrid Bulte, & Albert Pilot

## Abstract

*This chapter focuses on design-based research on generating design principles including the arguments, strategies and the intended pedagogical effects for the case of context-based chemistry education for pre-university students. In a teaching-learning process about macro-micro thinking, students have to link daily life phenomena to the learning of (formal) relations between structures and properties in chemistry. Procedural stages of the design-based research approach and data from two empirical cycles are used to illustrate how the elaboration of the argued strategy components we started with was refined to obtain a valid insight and knowledge claim in terms of a design principle and an evidence-based framework of teaching-learning phases. We present how we linked theories on design of learning and teaching with design principles to obtain a contribution to this specific body of knowledge through design-based research. This is followed by a reflection on the presented approach, the design principles and the validity of the approach.*

## 1. Introduction

There is a certain consensus about the typical procedural stages of a design-based research approach: design, systematic development and evaluation. However, these stages are seldom described in a reflective and systematic way (Blessing & Chakrabarti, 2009). A reflective and systematic description may give a fellow designer of teaching-learning processes insights into the decisions how to generate, to select and to validate design alternatives at a level at which they have consequences for learning (DiSessa & Cobb, 2004). It should also link existing theories about learning and psychological processes to the outcomes of design experiments (Nieveen, McKenney, & Van den Akker, 2006). Furthermore, the design-based researcher is required to provide a description how this insight developed into a knowledge claim.

The purpose of this chapter is to explicitly describe the procedural stages we followed, to reflect on our approach and to illustrate our approach for a case in context-based chemistry education in which students learn macro-micro thinking in which *submicroscopic* models are constructed to investigate, explain and use properties of known and new substances and their transformations at *macroscopic* level (Meijer, 2011). We report about the procedural stages we applied, e.g. the type of addressed (research) problems, the defined type of knowledge base, the degree to which the design was specified, and the way the intended effects were achieved. By making the procedural stages explicit, we aim to present how we did come to the formulation of design principles as a knowledge claim.

The chapter is structured in the following way: first, after a short description of the educational problem, we describe our approach at a general level in terms of a process in four procedural stages, aimed at defining and elaborating design principles as a knowledge base. Then, for each of these stages, the main activities and products in the case study are presented. The final part of this chapter presents a reflection on the approach and outcomes of each of these procedural stages.

## 2. The educational problem

In chemistry education macro-micro thinking is very difficult for students to learn. Macro-micro thinking is considered to be a key conceptual area in the domain of chemistry. It is concerned with the understanding and prediction of properties and transformations of materials. Chemists construct submicroscopic models for investigating, explaining and using properties of known and new substances and their transformations at the macroscopic level. The macro level refers to directly observable phenomena, e.g., colour, smell, conduction of heat or electricity, mass or taste. The sub micro level refers to models with structures at the level of molecules or atoms, or in general, invisible particles with a dimension of about  $10^{-9}$ - $10^{-10}$  m, much smaller than we can observe.

The difficulty of students to learn macro-micro thinking is described as a twofold problem (for a further analysis, see the section about the research clarification stage):

1. Students often have difficulty in relating macroscopic properties to submicroscopic models.
2. Students rarely experience sub microscopic models as relevant for explaining the world they live in.

## 3. The approach for design-based research used in this study

In our approach we distinguish four stages, which we have specified for the domain of education (Blessing & Chakrabarti, 2009).

1. *Research clarification stage* leading to an analysis of an unsolved educational problem and a sketch how to solve this problem.
2. *Descriptive stage* leading to a selection and review of relevant theories describing the assumptions necessary for a sketch to solve the problem, e.g. by identification of crucial factors or variables, resulting from available literature, earlier empirical explorations and/or practical experience of the members of the research team.
3. *Prescriptive stage* concretising the sketch to a solution by combining it with the theoretical assumptions. In this stage, it is described how and why the crucial factors or variables are used in the intervention and/or designed teaching-learning arrangement (the solution), including a detailed description of the arguments why and how a designed teaching-learning arrangement is expected to function as key components in an evaluation design. To be clear, we distinguish between the designed teaching-learning *arrangement* (prescriptive) and the realized teaching-learning *process* (descriptive).
4. *Evaluative stage* including an empirical study in which a teaching-learning arrangement is enacted and evaluated. The description includes an analysis of the enacted teaching-learning process in the classroom and the extent to which the intended teaching-learning arrangement is realized. This stage is to draw conclusions about the usefulness of (the strategies included within) the designed (prescriptive) teaching-learning arrangement and how it has functioned (the description of the realized teaching-learning process). It describes which further investigations or improvements are necessary. The conclusions provide input for a reflection on the effectiveness of the design principles.



These four stages are in fact one cycle in an iterative research approach. After the evaluative stage, a new cycle of description, prescription and evaluation takes place (see Figure 1, indicated by a redesign step: either step Y or step Z). We describe each stage to address the purpose of our study: to report about the approach we have applied for our case leading to the formulation of design principles as an explicit outcome of our research approach.

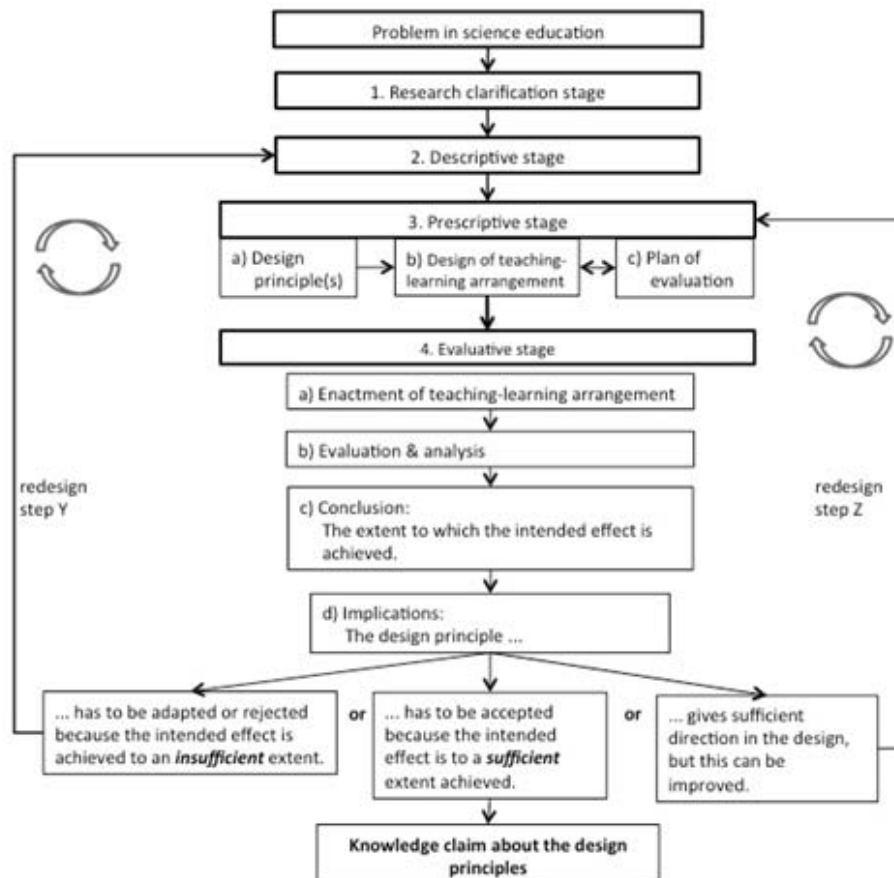


Figure 1: The method for DBR presented in this study

Design principles (Figure 2) form the core of our approach and describe how strategy components can be used to design a teaching-learning arrangement to achieve an intended pedagogical effect (Edelson, 2001; McKenney, Nieveen, & Van den Akker, 2006; Van den Akker, 1999). We consider empirically underpinned design principles as a knowledge claim. These design principles can be described as the result of the application of a design-based research approach. Pedagogical effect refers to learning aims (e.g. macro-micro thinking, modelling) and/or (affective) educational aims (e.g. relevance, evoking motives) of the teaching-learning arrangement.

A design principle is described with underlying *arguments* that relate the chosen *strategy* to the intended pedagogical *effects* as is schematically depicted in Figure 2. A strategy may contain one or more strategy components. The term *strategy component* refers to a potential arrangement or sequence of student' activities to be planned or executed within a teaching-learning arrangement to achieve certain intended pedagogical effects.

A strategy component is an answer to the question: *'what strategy, based on a theory or experience is expected to be effective in the teaching-learning process?'* The strategy components are derived from potential solutions, formulated in the descriptive stage, related to the problems which are mentioned in the stage of research clarification.

The term *arguments* refers to the relevant literature, to empirical evidence of previous research cycles and to practical experience of the designer and/or teachers which are necessary to justify and to underpin the chosen strategy components. In fact the arguments contain one or more hypothetical mechanisms which explain why it can be expected that the use of the strategy component or combination of simultaneous use of strategy components leads to the intended effects. The term *mechanism* refers to a hypothetical or proven functional relation (between an aim and means) or correlative relation (between an effect and a cause).

Design principles can be both descriptive and predictive in nature and are considered to be hypothetical; they need to be confirmed or refined. They can be adapted or replaced based on findings of the evaluation of a design cycle. A design principle has a heuristic nature (Plomp, 2009). It is an argued but heuristic guideline for the designer of teaching-learning arrangements about how and why a strategy component is expected to function and can lead to the intended pedagogical effects. Due to the intrinsic incompleteness of a design (Petroski, 2006), design principles are developed or refined during the multiple cycles of design, enactment, analysis and redesign.

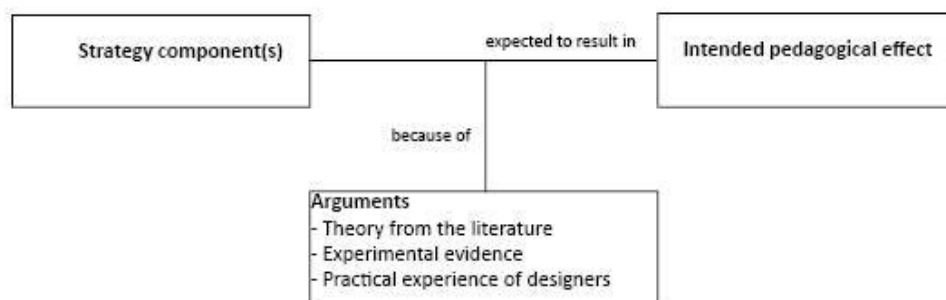


Figure 2: General presentation of a design principle

In the next sections, each of the procedural stages 1-4 is further explained and illustrated by the exemplary case in two cycles of description, prescription and evaluation.

#### 4. Research clarification stage

##### Analysis of an unsolved educational problem and a sketch how to solve this problem

In our case study *three problems* are important. First, students do not experience a connection between the phenomena in their lives and the chemistry theories, models and concepts they learn in school (Gilbert, 2006). Second, students do not experience why a preceding activity is followed by a next one during their study. They do their work as a result of the top-down guidelines as being presented to them by the teacher and/or the textbooks (Westbroek, Klaassen, Bulte, & Pilot, 2010). Third, at this moment chemistry education has not found a strategy to bridge the huge gap between the experienced phenomena in the real world, and the

abstract model descriptions of atoms and molecules which students experience as difficult to learn (Gilbert & Treagust, 2009). The step from observed phenomena (macro level) to the invisible entities at a scale of  $10^{-9}$ - $10^{-10}$  m (submicro level) is huge, for example from bread to protein molecules, and leads to cognitive confusion, such that students may give the sub microscopic entities the same properties as materials. The learning of this specific content is still problematic and unsolved in chemical education.

The *sketch of a solution* is as follows. To address the three problems, we chose to use adapted authentic practices as contexts (Bulte, Westbroek, de Jong, & Pilot, 2006) for making the learning of chemistry relevant for the students (Meijer, 2011). Based on the vision that the content (i.e. chemistry) should be considered as a human activity, scientific and technological developments are interrelated with issues in society and part of our cultures. We used the outcomes of a previous study on expert reasoning when they are addressing authentic tasks to integrate the specific content with the relevant authentic practices (Meijer, 2011).

We designed three authentic tasks in different fields, for example biochemistry, using research papers and other relevant literature. We consulted experts in the related professional authentic practices, who used their own specific expert knowledge to solve problems. We used both the literature and the empirical data from the expert consultations to reconstruct and redefine the content. As expected, experts included macro-micro thinking in their reasoning, although with a different focus and using different models compared to traditional chemistry education at school.

The use of mesoscopic levels as models in between the macro and sub micro and their interrelations could be useful to address the third problem. In Figure 3, mesoscopic levels are presented as the structures at scales in between bread at macro level as an observable entity (scale:  $10^{-1}$  m) and the molecules at submicro level (scale:  $10^{-10}$  m). These mesoscopic levels are not presented in traditional secondary chemistry education.

In this stage of our design-based research approach, qualitative research instruments are used such as document analysis and peer review, semi structured interviews with students; these data sources were analysed by two researchers independently.

## 5. Descriptive stage (cycle 1)

### **Selection of relevant theories describing and underpinning the assumptions necessary for a sketch to solve the problem**

The selection of key strategy components needs two theoretical perspectives: a) the selection of a teaching-learning theory to address the first and the second problem b) a process to analyse and redefine the content for addressing the third problem.

#### **a. The selection of a theory for teaching and learning**

With respect to the first problem, we selected the cultural historical approach (Van Oers, 1998) as a theoretical starting point. Consequently, we chose to position teaching and learning within an authentic social practice as context (Bulte, Westbroek, de Jong, & Pilot, 2006). We argued that students will be enabled to construct meaning in connection to the concepts they learn, when they can connect their learning of the concepts to relevant social practices, for example related to foods, medicines, material science.

The second problem, the lack of motives of students to perform teaching-learning activities in a certain sequence, is connected to the first problem. We argued that through a relevant outline of a sequence of teaching-learning activities within a relevant context, students come to see why to proceed to a next activity. If students are provided with a specific (learning) task which is adapted from the social practice to make it relevant in students' perspectives, they intuitively see what, why and how to achieve this task (Van Oers, 1998). In this way, students have a motive to perform each of the teaching-learning activities because they experience each of them as necessary.

In educational research, specific causal or functional relations between strategies and effects (mechanisms) which are needed for design decisions are frequently not available due to the complexity of the education situation (Plomp, 2007) and that theories of learning and teaching are context related (Ryan & Deci, 2000). For example, causal relations are missing between relevant variables: the motives of students, the productive use of their intuitive notions, the selection of (learning) tasks, the procedural steps to accomplish such tasks, a balance between students' freedom and teacher guidance and the intended effects: learning abstract concepts and performing activities. Within the chosen theoretical perspective for the design of the teaching-learning arrangement, students and teacher are considered as a community of practice in which students have ownership of one complex task. It requires a teaching-learning arrangement with a subdivision into several (teaching-learning) phases which are derived from an adapted procedure of an authentic practice.

#### ***b. Analysis and redefinition of the content***

The theoretical perspective of authentic social practices as contexts for learning requires a *new conceptual analysis of the content* with regard to the content problem, such that the reconstructed and/or redefined content can be incorporated into a teaching-learning arrangement in the classroom (Bulte et al., 2006). As is the case in the model of educational reconstruction, a new conceptual analysis is an integral part of our research approach, as it will be in many domain specific design-based research studies. In this case, the re-orientation on the chemistry content is focused on the specific content of macro-micro thinking. However, in other studies such a re-orientation also forms an essential part of a design-based research approach, e.g. for the case of modelling in science (Prins & Pilot, this volume).

In traditional chemical education, macro-micro thinking focuses on the particulate nature of substances in terms of molecules and atoms. In this way, macroscopic phenomena such as the different properties between gases, liquids and solids, can be explained. However, the proposed models are not suitable to explain or understand many everyday properties such as the elasticity of an elastic band, the strength of a wall, the deformation of dough, elongation, fracture, and so on (see figure 3). Nor are the models suitable to address real authentic tasks positioned within authentic practices. With a traditionally defined content, students do not come to know that properties emerge from structures within a material that are not directly related to molecules and atoms. The contents lack models that relate properties to structures at intermediate (size) level. For example structures such as treads of polymer fibres in coats are respectively related to properties as the waterproof protection of gore tex. Because the research for this important problem in science education did not provide solutions we did search for a solution within authentic practices related to the specific science domain (see Meijer, 2011).

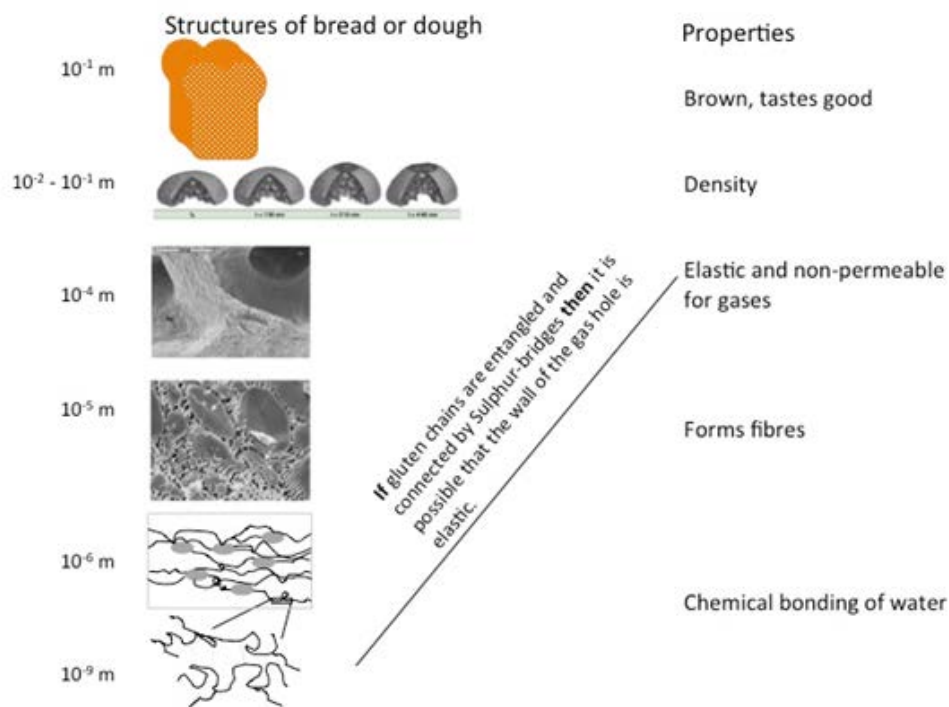


Figure 3: A conceptual schema of structures (or models at small scales) in bread connected with a scale and properties. This figure contains one example of a structure-property relation

## 6. Prescriptive stage (cycle 1)

Concretising the sketch to a solution by combining it with the theoretical assumptions, it is described how and why the crucial factors or variables are used in the intervention and/or designed teaching-learning arrangement, including a detailed description of the arguments why and how a designed teaching-learning arrangement is expected to function as a key component in the evaluation design.

### a. The formulation of initial design principles and research questions

First, to formulate the design principles, we describe key strategy components, underlying theoretical arguments and the intended pedagogical effects. These three elements together form a design principle (Figure 2; McKenney, Nieveen, & Van den Akker, 2006). This activity also involves the formulation of the research questions.

In our approach, the formulation and evaluation of design principles were used to develop a model for a specific teaching-learning arrangement, and to reveal the underlying vision and assumptions (the 'why') and the use of design principles (the 'how'). The list of strategy components may be longer, however only necessary conditions for the elaboration of a strategy component in the instructional designs should be incorporated. In this way, the strongest relation to the intended effect should be chosen. To obtain a clear and simple model which can be handled by the designer, the number of strategies components should be restricted. We developed three design principles related to 'context', 'sequence' and 'content', which are addressing the three-fold problem described in the research clarification stage.

The context-principle deals with the strategy to set up a social practice as a context to increase the relevance of learning macro-micro thinking for students.

The sequence-principle focuses on strategies to realise a sequence in which students have a motive to perform every teaching-learning activity to achieve the goal of the learning task (second problem). The content-principle is related to strategies on how the content-related part of macro-micro thinking can be incorporated into the teaching-learning arrangement (third problem). The principles are interrelated and influence each other to some extent, but for a clear presentation we prefer this simplified categorization.

### **Context-principle**

The *arguments* for the development of the context-principle are based on theories on social practices (Vygotsky, 1978; Wenger, 1998). Using these theories, we focused on an authentic practice which is defined as a homogeneous group of people in society working on real-world chemistry problems and societal issues in a 'community' (e.g. a team of researchers or designers, working on a common problem), connected by three characteristic features: common motives and purposes, working according to a similar characteristic procedure and using similar background knowledge about the issue they work on (Bulte et al., 2006; Prins & Pilot, this volume).

In an authentic practice, activities and conceptual knowledge do form a coherent whole. According to Van Oers (1998), the context emerges into the existence in the interactions of students when it becomes clear what kind of task is to be accomplished (strategy component i). The procedural steps, how to accomplish the activity should be based on the intuitive notions of students (strategy component ii). In that case, the procedural steps can be seen as relevant from the perspective of the students. Students will become members of a community by involving engagement to the task (Wenger, 1998). To improve the engagement, productive interaction is needed which means that students have to share personal experiences, references and memories with others (strategy component iii) which also increases the forming of a community. There is a need to pay attention to the students' input and self-regulation. This initial context-principle to design a context as an address to the first problem is formulated as (see further Meijer, 2011):

If students as participants of a community of practice within the classroom are provided with a practice-related task (*strategy component i*) **and** have their own plan of action based on intuitive notions (*strategy component ii*) **and** productive interaction is enabled (*strategy component iii*) **then** a context is established at the start of the teaching-learning process as a condition to make the learning of chemical concepts relevant to students (*intended pedagogical effect*).

### **Sequence-principle**

The sequencing of the teaching-learning activities should be such that students recognize the steps in the characteristic procedure which is necessary to accomplish their task in the authentic practice. For educational purposes, the activities within the authentic practice need to be adapted, because students do not have the experience of experts and the students are involved in learning activities towards a specific learning goal and assessment. The design of the teaching-learning arrangement involves the adaptation of the characteristic procedure consisting of adding specific steps to introduce new information, experiments and reflection activities to achieve the learning goal (strategy component iv).

The *intended effect* of this design principle is to realize a teaching-learning process in which students know 'why what to do next' when proceeding from one activity to the next (mentioned as the second problem of this case study). Therefore, the designer should sequence the anticipated students' motives to enable students to proceed from one activity to a next one (strategy component v).

So they know at every moment within the teaching-learning process why they have to perform a teaching-learning activity in order to accomplish their task (Lijnse & Klaassen, 2004). To be concrete, students recognize and go through the procedure: exploring the problem, subsequently finding an explanation for this problem, followed by the purposeful design and evaluation of the product in several cycles.

### **Content-principle**

Following the newly reconstructed conceptual organisation as an outcome of the descriptive stage, we described macro-micro thinking using systems thinking (strategy component vi) as presented in figure 3. In the case that a cause of a property should be explained, students need to search this in the nature of the material itself (strategy component vii). This intuitive notion about a cause of a property was used as an explanatory framework of the natural world (Harré et al., 1975). So, to explain or to understand a certain property, students have to identify the structure that causes this property. For example, the elasticity (property) of a wall of a gas hole could be explained by the existence of gluten chains that are entangled, enrolled and entwined. The wall is not a massive one but is built up from chains (structure) that could move to a certain length along each other. In this way, structure-property relations are the connections between the macro, meso levels and if necessary to the sub-micro level. To design a teaching-learning arrangement to realize the intended pedagogical effect, a content-principle was defined (Meijer, 2011).

The design principles constitute an important part of the knowledge claim of our study. At this meta level, it seems that the design principles are not entwined. However, when the strategy components of the design principles are elaborated at the level of teaching-learning activities, design principles form an interrelated system, incorporated within a teaching-learning arrangement with specific learning phases. The design principles form a nested system; e.g. the context-principle is conditional for both sequence and content-principle.

Because the context-principle is conditional for the both sequence and content-principle, we illustrate the research approach with the first strategy component of the context-principle only. Connected to a concretized teaching-learning arrangement as an elaboration of the design principles, the research questions have the form: '*To what extent does the elaboration of the strategy components lead to the intended effect?*' and '*What is the empirically underpinned design principle?*'

### **b. The design process of the teaching-learning arrangement; elaborating the strategy components**

The design of the teaching-learning arrangement starts by using a framework of teaching-learning phases, with functions of each learning phase, together with general expectations about how the learning phase will function in relation to the main goal of the learning process (second column in table 1). The functions of the learning phases are a direct consequence of the chosen theory for teaching and learning, that is, an orientation of the practice-related task of the authentic practice is a necessary first step.

In our case the teaching-learning arrangement of cycle 1 consists of six teaching-learning phases: orientation, definition of the task, extension of knowledge, use of knowledge, reflection on design and thinking process, and reflection and transfer (Meijer, 2011).

Next, the learning phases are made concrete into a detailed outline of teaching-learning activities, accompanied with the theoretical or experiential arguments about why and how the teaching-learning activity will function as described by a detailed set of expectations. The whole set of expectations together describe the intended effects.

The concrete expectations result from the elaboration of the strategy components; they may be connected to one or more strategy components (Table 1). The framework of teaching-learning phases is a 'model' for the teaching-learning process. Each of the phases consists of one or more teaching-learning activities together with the detailed expectations for each activity.

In our case, the context-principle demands that specific choices are made for the type of authentic practice, the specific exemplary task, and the focus with which the task is addressed. We chose the following task for students: to acquire more knowledge about the development of gluten-free food products. There were two arguments for this choice. First, the relatedness with disease, people and food are close to the students' daily life (students were 17 y, pre-university level, grade 12). Second, students need the specific content of macro-micro thinking with structure-property relations to achieve their task. Therefore, the context has to be the practice of developer of food products. In that practice, the task, the procedure to accomplish the task, and chemistry concepts and macro-micro thinking are relevant. The concretized outline of the designed teaching-learning arrangement in cycle 1 is described below: the elaboration of the strategy component i of the context-principle 'select a task' (see Table 1).

In the orientation phase of the teaching-learning arrangement, the task included the presentation of the fact that about 1% of the human population has gluten intolerance. The initial setting was elaborated as a possible business idea of a virtual senior co-worker of a food company intending to develop gluten-free food products for the target group as a model of a realistic authentic practice. As participants in such an authentic practice, the students as junior developers of food products had to formulate their own proposal for a new project for the company to develop one of the gluten-free products as an example: bread based on corn instead of wheat.

For the development of gluten-free food products, the removal of gluten from wheat is far too complicated to perform in secondary education, so corn was presented to students as a useful replacement for wheat. The use of corn, however, leads to low-quality bread. Gluten consists of proteins which form an elastic network (structure) which can capture the carbon dioxide gas (property) that is formed during fermentation of the yeast (see Figure 3). Due to this property of the gluten network, the dough will rise, eventually producing an acceptable quality of bread. Therefore, students had to find a replacement for gluten to add to the corn dough. Based on the given information about structures, students should be able to select a replacement for gluten by looking for structures in other substances which are similar as in gluten. These structures could cause probably the necessary properties to replace gluten. These structure-property relations are an essential part of macro-micro thinking. For understanding this relationship, the students had to notify that they needed to know more about the ability of wheat dough to capture gasses at the start of the teaching-learning arrangement.



On the basis of the arguments for the design, the detailed expectations can be described as concrete realisations of the intended pedagogical effect (see table 1). As a consequence, the plan of evaluation contains these concrete descriptions of the expectations.

**c. Formulation of the plan of evaluation, the planned enactment, and data collection and analysis**

In the evaluation plan, the expectations are written in concrete observable behaviour of students or formulations of students' answers, statements or other outcomes (see examples in Table 1). For each learning phase, the expectations are related to the strategy components. The expectation about a shared motive to accomplish the task was formulated as concrete observable behaviour, e.g. as enthusiastic reactions of students and focused actions of students to complete the task.

Besides the complete set of expectations related to the elaboration of the three strategy components, the *plan of evaluation* is completed with appropriate instruments for data collection and protocols for data analysis.

*Table 1: The context-principle with strategy components and intended effects concretized into detailed expectations embedded within the teaching-learning phase 'orientation' for cycle 1.*

Learning phase	Expectation of phase	Context-principle Strategy component	Detailed expectation
I Orientation	Students experience the relevance of the task to design gluten-free corn bread as exemplarily of a class of food products because people have coeliac disease.	i. Select a task  ii. Use intuitive notions of students with regard to procedural steps  iii. Enable productive interaction between participants	a) Students recognise the socio-scientific task, which becomes relevant for them. b) Students recognise that the practice-related task exists within an authentic practice; students develop a shared motive to accomplish the task.  a) Students restrict the task by zooming from a range of food products into bread and use corn instead of wheat. b) Students have a notion about the main procedural steps of the development process: exploring the problem, finding an explanation, designing and evaluating. c) Students are able to extend their notions about the procedure with the use of a replacement for gluten and knowledge about baking bread.  a) Students experience being able to influence the task and the process to accomplish the task. b) Students become participants in the community of practice by accepting their role as junior designers of food products.

## 7. Evaluative stage (cycle 1)

In this evaluative stage a teaching-learning arrangement is enacted and evaluated. The description includes an analysis of the enacted teaching-learning process in the classroom and the extent to which the intended teaching-learning arrangement is realized. This stage is to draw conclusions about the usefulness of (the strategies included within) the teaching-learning process, how it has functioned and which further investigations or improvements are necessary. The conclusions provide input for a reflection on the effectiveness of the design principles. The product of this phase is a thick description in which the findings are presented as the evaluation of all concrete expectations, whether these are achieved or not achieved; subsequently, the conclusions are formulated.

As an implication, the designed teaching-learning arrangement as elaboration of the strategy components and the formulation of the design principles need to be part of discussion when the intended pedagogical effects are not fully achieved. If necessary the formulation of the strategy components and consequently the design principles, as a contribution to the body of knowledge, together with the designed teaching-learning arrangement needs to be adapted or refined.

### **a. The enactment of the teaching-learning arrangement in the classroom and collection of data**

Enactment of the teaching-learning arrangement in the classroom takes place by a well prepared teacher. In the first cycle, the teaching-learning arrangement was enacted with a small number of representative students in a small scale setting, because this case study has an explorative character. In this case we involved 8 students (17 y, pre-university level, grade 12) and one teacher.

During the enactment, the researcher needs to collect the data by using multiple sources and observes what actually happens in the classroom while the teaching-learning arrangement is enacted. The data sources to be used were video and voice recordings, observations and field notes, questionnaires before (pre-questionnaires) during and after enactment (post-questionnaires), students' work, and interviews with students and the teacher.

### **b. Data analysis, including validation strategies**

The process of in-depth analysis of the data makes high demands upon the method, the protocols for analysis and coding, and the validation strategies to address the issues of objectivity, subjectivity, reliability and validity.

Data collection and analysis are mainly qualitative, although also quantitative methods may and can be used where appropriate. Creswell (2007, p. 207) considers 'validation' as an attempt to assess the 'accuracy' of the findings. This accuracy improves when researchers know the culture of the research field to interpret the observations in the right way (issue of subjectivity), by triangulation of multiple data sources, independent analysis by two researchers (issue of reliability) and, by using a thick description to enable readers to transfer the information into other settings.

In this case, we determined to what extent the intended pedagogical effects were achieved by using the set of detailed expectations as a framework for analysis. The data were analysed by comparing the actual activities and effects with the set of detailed expectations by two researchers independently.

Triangulation of data sources took place to increase the validity of the findings. Video and voice recordings together with the field notes of the researcher provided a first analysis of the enacted teaching and learning activities and a detailed description of what takes place in the classroom. The whole group of students was taken as the unit of analysis. The number of students who act as intended, their behaviour and their active involvement during classroom discussions, interpreted using the operationalised criteria, was counted using data sources, field notes, video and voice recordings. A further 'thick description' was obtained by using copies of the work of the students, post-interviews, and questionnaires. In-between-questionnaires were especially designed to verify whether the students had a perspective of the next teaching-learning activities. This 'thick description' was compared with the intended teaching-learning arrangements, described in detail by the set of expectations (fourth column in Table 1).

The extent to which the expectations are realised were reported on a three-point scale using the terms 'not', 'partly' or 'fully' achieved. If only one or two of the students act according to the intended expectations, we used the term 'not achieved'.

'Fully achieved' means that at least 6 out of 8 students (80 per cent) acted according to at least 80 per cent of the expectations (Juran, 1974). This is considered sufficient for the explorative purposes of the case study. The term 'partly' refers to outcomes in between 'not achieved' and 'fully achieved'. For each detailed expectation, the extent of achievement was determined. To formulate the findings, the researchers zoomed out from detailed expectations of each teaching-learning activity to overall expectations of the teaching-learning phases focusing on the teaching-learning process at the level of the strategy components and the design principles. Then, a conclusion was drawn about the effect of each strategy component and the research questions could be answered.

### **c. Findings and conclusions**

Conclusions are drawn about the usefulness of the strategies included within the teaching-learning process, how this process has functioned and which further investigations or improvements are necessary. The conclusions provided input for a reflection on the effectiveness of the design principles and the precise answering of the research questions.

This part of the approach is illustrated by a description of the findings and conclusions of our case with respect to the first strategy component (select a task) of the context-principle, here for the first cycle. The expectations, as concretized intended effects, were: (i-a) students recognised the socio-scientific task, which became relevant for them, and (i-b) students recognised that the practice-related task exists within an authentic practice; students developed a shared motive to accomplish this task (Table 1).

We found that expectation i-a was 'fully' achieved. Students recognised the socio-scientific task and it was relevant for them (voice and video recording activity 1, cycle 1). The motivation of students to participate in this project came to the fore in the first group discussion at the beginning of the teaching-learning process (voice and video recording activity 1, cycle 1). The coeliac disease problem was important for three students (S1, S3, S4). Two students (S4 and S5) had family members who suffered from the disease. Two others (S7 and S8) knew that gluten-free products are sold because they worked at a bakery. During the group discussion, all students displayed the insight that coeliac disease is a problem for people (voice and video recording of activity 1, cycle 1).

Although students recognised the task of developing gluten-free bread, this only 'partly' evoked a shared motive to accomplish the task (expectation i-b; voice and video recording of activity 3 and questionnaire after activity 4). First, only two students showed the intended motive to accomplish the task: a formulation that can be considered as a motive was expressed by students in wording such as 'we have to develop something' and 'if we develop a new product' and 'we also want people to buy our product'. This was interpreted as a sense of ownership of the task. Second, a clear focus of the task was lacking in all descriptions formulated by the students. The task we selected was relevant from students' perspectives; however, we did not manage to evoke a shared motive due to the diverse interpretations of students about the task.

With respect to the strategy component i, 'Select a task' (table 1), we concluded that it was partly effective. As designers we did not manage to develop a shared motive for the accomplishment of the task (i-b), although the students experienced the task as relevant (i-a). We concluded that the task in cycle 1 did not have a clear *focus*. Therefore it was not well defined for students what exactly they had to accomplish.

#### **d. Implications**

As it appeared necessary from the findings and conclusions, the formulation of the strategy components and consequently the design principles and the teaching-learning arrangement needed to be adapted or refined. This should provide a further contribution to the body of knowledge.

This part of the approach is also illustrated by a description of the implications in our case with respect to the first strategy component (select a task) of the context-principle, here for the first cycle. An implication resulting from the given conclusion was that the task had to be clearly *focused* on the *design process* of a *class* of gluten-free food products to gain knowledge about the properties of gluten for designing food products. In this way, the task should evoke a broad motive to start with. As a consequence of the *focused* practice-related task, we argued that the necessary steps to accomplish the task are more easily evoked in students in an intuitive way. Secondly, the use of an external motivational aspect, e.g., an external supervisor as a member of the authentic practice, should introduce the issue to the students and could thus keep the students more *focused* on the goal of their task. Both students and teacher are then framed by the goal of their task.

Summarizing, the effect obtained in design cycle 1 was not as intended. The strategy components showed potential to achieve the intended effect; however, the elaboration into the designed teaching-learning arrangement did not lead to the intended effect to a sufficient degree. The implication was that the formulation of the strategy components needed improvement although we did not have to add one or more strategy components in the design principle. As a result, the context-principle had to be refined. This illustrates the feedback loop from the evaluative stage to the descriptive stage (figure 1: redesign step Y).

### **8. Descriptive and prescriptive stage (cycle 2)**

Based on the results from cycle 1, with increased understanding of the design problem and additional literature, the teaching-learning arrangement was redesigned. The new context-principle was formulated as (the new element 'focused' in italics): **If** students as participants of a community of practice within the classroom are provided with a *focused* practice-related task (strategy component i) **and** have their own plan of action based on intuitive notions (strategy component ii) **and** productive interaction is enabled (strategy component iii), **then** a context is

established as a condition to make the learning of chemical concepts relevant to students (intended pedagogical effect), see Meijer (2011).

The (second) prescriptive stage is illustrated for strategy component i only. The adaptation of strategy component i led to a reformulation of the detailed expectations (see italics in right column in Table 2).

*Table 2: The context-principle with strategy components and intended effects concretized into detailed expectations embedded within the teaching-learning phase 'orientation' for cycle 2*

Learning phase	Expectation of phase	Context-principle	
		Strategy component	Detailed expectation
I Orientation	Students experience the relevance of the task to design gluten-free corn bread as exemplarily of a class of food products because people have coeliac disease.	i. Select a <i>focused</i> task	(a) <i>Students accept the task of designing a class of gluten-free food products as realistic and understand that it is necessary to accomplish the task for people with coeliac disease.</i>  (b) <i>Students have the opportunity to participate by developing a shared motive to accomplish the task.</i>

## 9. Evaluative stage (cycle 2)

The teaching-learning arrangement of cycle 2 was enacted with new students and another teacher. The expectation about the relevance of task (i-a) was 'fully' achieved. Expectation i-b about students' development of a shared motive was 'fully' achieved. The goal of the task was clear to students. With regard to strategy component i it could be concluded that the task was perceived as relevant by students. From the analysis with regard to the expectations related to all three strategy components, it was concluded that the task alone and not the use of a fictive company were sufficient to make the learning relevant for students. The chosen design procedure could be evoked intuitively by students. However, the chosen procedure did not lead to the intended goal to gain knowledge about the study of designing a product as was intended. The procedure leads to a product which is the usual and intuitive end of a design procedure. A conceptual design procedure leading to a concept of the product could be more useful to make the related knowledge explicit (see Meijer, 2011).

The elaboration of all strategy components led to a sufficient degree to the intended pedagogical effect: for students the context of an authentic practice for learning chemistry is relevant. We concluded that we had come to the formulation of an empirically underpinned context-principle. More details about the three design principles are described by Meijer (2011).

## 10. Reflection

The purpose of this chapter is to describe our approach/model to structure and plan design-based research in science education that provides outcomes in the form of empirically underpinned design principles. We now present a reflection on the approach, the design principles, the validity of the approach and end with a general discussion.

### Approach

In our case study, the presented DBR approach is used as a method to understand 'why' and 'how' design principles are successful instruments to guide possible solutions for a certain educational problem, by explicitly presenting the *generation* and *improvement* of the knowledge base in terms of these design principles (McKenney et al., 2006; Nieveen et al., 2006). There are two arguments for this.

First, the described process of elaboration of and refinement of strategy components can be considered as theory building (Van den Akker, 2006) since the formulation of (additional) strategy components is theory driven (Burkhardt, 2006; DiSessa & Cobb, 2004). Second, the understanding of the cultural historical approach and the knowledge about how to use this approach within chemistry or science education is improved (the 'why') because it is described in an argued way how parts of the cultural historical approach were successfully incorporated into an teaching-learning process ('the how').

We have to mention an important issue in relation to the stages of the presented approach. The choice of a specific learning theory as theoretical background influences the concretising of the four stages (Barab & Squire, 2004). During the description of the prescriptive stage when the teaching-learning arrangement is designed, we find a strong influence of the theoretical background on the elaboration during the selection of strategy components and the formulation of design principles. As a result of the choice of a cultural historical approach as theoretical background for learning, the activities of students, tasks and procedures have a central place in the design (and the design principles). The formulation of design principles and the selection of strategy components will be different when a design is based on other theoretical backgrounds e.g. a conceptual change approach.

The cyclic character of DBR becomes visible with the redesign steps Y and Z (figure 1). In this study, the redesign step Y is illustrated by the detailed description of one strategy component of the context-principle. A more extensive description of the arguments with regard to the sequence-principle and the content-principle is described by Meijer (2011). In the situation that the intended effects are fully achieved, a detailed described explanation for the use of strategy components can be found in the 'why' and 'how' sections of the design. When the conclusion is 'not achieved', the strategy component or its elaboration do not function well or do not have the intended effect. Then there is a need for a reconsideration of the theoretical background. When the intended effects are partly achieved, the elaboration of the strategy components can be refined or adapted, and therefore the design principle could change. However, there must be indications that the intended effect could be achieved by using the strategy components or by replacing or adding strategy components. In the case when the design principle needs to be adapted, new theoretical insights or background due to a better understanding of the problems is necessary for a theory-based description of this new principle. This can lead to add new strategy components to or replace one in the design principle, as was the case for the content-principle.

Most of the presented methodological stages can be recognized in other studies in which design-based research is used as method (Cobb et al., 2001; Komorek et al., 2004; Meheut, 2004; Psillos et al., 2004; Prins and Pilot, this volume). In most of these studies solutions for a specific educational problem are developed, enacted and refined. Probably these studies can be best described as evidence-based problem solving by using design research or validation studies in which a possible solution is *proofed* (Nieveen, 2009). This is a worthwhile contribution for educational problems.

However, a specific knowledge claim as a contribution towards the development of a knowledge base remained to a large extent implicit.

### **Design principles**

As part of the knowledge claim, we have developed three empirically underpinned design principles which appeared to be useful to design a teaching-learning arrangement in chemistry education. The question is, whether the empirically underpinned design principles are useful to design other teaching-learning arrangements within science education. According to Plomp (2009), the heuristic design principles will prove to be additionally powerful if they have been validated in the successful design of other similar interventions in various contexts. The same research approach was successfully applied in a case study by Prins and Pilot (this volume). However, to generalize the resulting strategy components and intended effects further studies are needed.

The value of these design principles is restricted by the situation in which they are validated, e.g. the chosen science content and the chosen learning theory. However, when applied as heuristic guidelines, we think that the presented design principles offer a worthwhile contribution to the field of science education because it gives insight in selecting and validating design alternatives at the level at which they are consequential for learning (DiSessa & Cobb, 2004). It can help designers and teachers to select and apply the design principles and framework presented in table 1 in their own settings (McKenney et al., 2006).

### **Validity and rigour of the outcomes**

The knowledge claim of the case study with the presented approach can be twofold. The first knowledge claim can be the design principles based on the evidence of a valid process of refinement or/and adaptation, although it was based on the data of only eight students. When the elaboration of the strategy components indeed lead to the intended effects in a sufficient extent, a better understanding of the design is achieved and a possible way of using theoretical background is better understood through refinement. Evidence based acceptance or rejection of (parts of) the theoretical background is an important outcome of this approach. The second knowledge claim can be the framework with the learning phases (see table 1) and the evidence-based understanding of this framework. This can be useful for the design of other teaching-learning arrangements. It can be a design tool, which clarifies the decisions in the design process and most important, it can provide a detailed insight into the teaching-learning process, the essential parts of the design, and the way it is designed or constructed in detail.

The knowledge claim that can be obtained by the presented approach is acquired in a valid way through three activities. The first activity is the construction of a clear and valid description of the arguments and how these arguments lead to the design choices with regard to the design principles as hypothesis. The presented approach asks for insight in the connections between theoretical perspective, and strategy components to achieve the intended effect in the form of design principles (see Table 3).

Second, the choice of qualitative and quantitative instruments is part of common instruments (third column in table 3), if these are used in the accepted valid way. Third, the validity is increased by using three validation strategies: triangulation, a thick description and peer review. For a valid study at least two validation strategies are necessary (Creswell, 2007; p. 209).

*Table 3: Stages and activities and research instruments in each stage used in this case study*

Stage	Activities within each stage	Qualitative or quantitative instruments in educational research
1. Research clarification stage	Analyse the educational problems Sketch a new strategy to address the reported problems	Review the literature
2. Descriptive stage	Select a theory of teaching and learning Analysis and redefinition the content	Analyse documents with respect to content Interview experts related to specific content Produce independent coding of the statements of the experts by two researchers Undertake a peer review
3. Prescriptive stage	Formulate initial design principles and research questions  Design a teaching-learning arrangement:	Produce a detailed description of the design  Use a framework of teaching-learning phases Elaborate the strategy components  Describe a model of the teaching-learning arrangement  Formulate expectations Formulate a plan of evaluation as a framework for analysis
4. Evaluative stage	Enact the teaching-learning arrangement and collect data Analyse data and use validation strategies  Formulate findings and draw conclusions Formulate implications and improvements (redesign step Y or Z)	Interpret the video and voice recordings, and written data Triangulate data sources Produce a detailed 'thick' description Undertake a peer review



The improvement of the design had not been possible by using a traditional approach in qualitative research. The way of obtaining a knowledge claim in design-based research differs from the five accepted approaches: case study, phenomenology, grounded theory, narrative research and ethnography (Creswell, 2007).

Design-based research can be considered as a new approach with its own approach (Plomp, 2009), although some questions arise about the role of context (Barab & Squire, 2004), formative evaluation and objectivity of the researcher when he or she is also a designer (Nieveen, 2009). Within this respect, this study is a contribution to explicitly describing the research stages of this approach. Because the high quality of engineering constructs in other fields like industrial design or mechanical engineering is not obtained by a single study or by using only physical and mathematical laws (the metaphor that Petroski used, 2006), the cyclic approach of this study can be considered as a valid step by step demonstration of a proof of principle (Freudenthal, 1991; Petroski, 2006). We have illustrated a process of improvement and refinement through failures that have been uncovered by a detailed analysis. This process is naturally incorporated in the educational design process and can lead to new fruitful educational innovations (Petroski, 2006) as a contribution to the body of knowledge in science education.

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## How to Utilize a Classroom Network to Support Teacher Feedback in Statistics Education

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# 32. How to utilize a classroom network to support teacher feedback in statistics education?

Jos Tolboom & Wilmad Kuiper

## Abstract

*By decreasing the amount of contact time during the past fifteen years in mathematics education in senior secondary education in the Netherlands the issue of organizing this contact time more efficiently has become increasingly relevant. Research shows that feedback is one of the most powerful tools for enhancing learning achievements. At the same time educational technology emerged in the field. Especially mobile technology seems to be promising. The main research question to be answered in this chapter is: "What are the possibilities of a wireless classroom network to support upper secondary statistics teachers in giving feedback?" An intervention was designed and evaluated that tries to utilize a classroom network of graphing calculators for the sake of feedback. The intervention was (re)designed and evaluated in four empirical educational design research cycles. The study was carried out in the domain of descriptive statistics. The study explicates the conditions to be fulfilled for the intervention to be successful.*

## 1. Introduction to the problem

### What is the problem in context?

The inducement of this study was a 1998 curriculum reform in senior secondary education in the Netherlands. This reform encompassed new learning goals and contents, reallocation of the aimed study load as well as pedagogical changes. The suggested pedagogical change aimed at students working self-regulated, deliberating in small groups and/or working individually on problems, with the teachers walking amongst them, available for consultation. This represents a change in the role of the teacher from 'a sage at the stage' to 'a guide by the side'.

In order to create time for teachers' coaching activities, school managers often decided to reduce time for the traditional face-to-face teaching practices. Teachers and students experienced an increase in workload (Van Streun, 2001). But there are more reasons than just reallocation of teaching time to embark on this study. Mathematics, the overarching learning domain of this research, is perceived by students to be difficult (Berch & Mazzocco, 2007; Geary, 2010; Hembree, 1990; Küchemann, 1981; Rosnick & Clement, 1980). There is a variety of problems that students may encounter when learning mathematics, such as: *dyscalculia* (McCloskey, Caramazza, & Basili, 1985), *innumeracy* (Paulos, 1988) and *mathematics learning disability* (or: *deficit*) (MLD) (Ginsburg, 1997). Especially poor performing students in mathematics consider statistics, the specific learning domain of this study, to be difficult (Hong & Karstensson, 2002). One interpretation of 'difficult' can be 'difficult to study without any help'.

The question then rises: What can we add to mathematics education to support students in understanding this difficult subject? This question prompted the study reported in this chapter.

### Why is EDR an appropriate research approach?

The aim of this study was to find out *if*, and if so, *how*, the supply of feedback in mathematics education can be improved by using a wireless classroom network (CN) of graphing calculators (GC). Several authors (Kelly, 2003; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006; Van den Akker & Kuiper, 2008) argue that educational design research (EDR) is appropriate for investigating this kind of improvement processes. Our main research question starts with *what*, implicating a *how*, that is: exploring a mode. After having underpinned this mode, we eventually tried to find out *why* our intervention succeeded or failed with respect to its goal. EDR is supposed to be a logical paradigm for this type of research. Kelly (2007) states that design research is most appropriate for *open wicked* problems (Rittel & Webber, 1973). Our problem is *wicked*, because feedback, although a classical theme in learning science, is still not completely understood (Cohen, 1985; Shute, 2008) and not very well structurally implemented in classroom practice. Our problem is *open* since it is highly unlikely that there is just one way to just one right answer. What is more, the technology we explored and its use were quite new, so we presumed we needed several iterations in order to create a teaching-learning setting specific enough to yield data that could possibly lead to an answer to our research question.

### What kind of EDR is applied in this study?

Nieveen, McKenney and Van den Akker (2006) distinguish the nature of EDR in two, more or less complementary, approaches:

1. validation studies, aiming at developing, elaborating, and validating theories about both the process of learning and the resulting implications for the design of learning environments;
2. development studies, aiming at the derivation of design principles for use in practice.

The study we describe falls into the second category. How did we apply the approach of EDR, eclectic in its nature (Gravemeijer, 1994), in this research? After having sharpened our focus with an initial study, we conducted a literature study with respect to feedback, statistics education and information and communication technology (ICT). Next, we formulated principles that guided the design of a prototype of the intervention. We conducted a content analysis of two predominantly used mathematics textbooks with respect to whether these textbooks focussed strong enough on 'data literacy'. With the design principles, and the conclusions from the content analysis, we developed a prototype including corresponding so-called 'hypothetical teaching trajectories' (HTT). The design of the prototype was reviewed by field experts focussed on the question 'Does this prototype facilitate the teaching and learning of 'data literacy' with an emphasis on feedback?' We adjusted the prototype to their findings. We evaluated the prototype in classroom practice using student questionnaires and interviews with

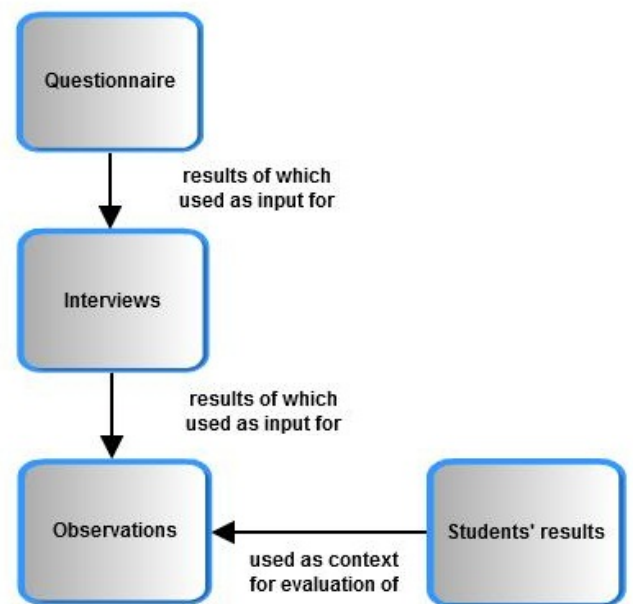


Figure 1: Data sources for this study



teachers and students. Analysis of these data offered input for a revision of the prototype. Again, the prototype was reviewed by experts and again adapted. Following this process the prototype was piloted in practice using the same evaluation techniques: observation, questionnaires and interviews.

The data sources are depicted in Figure 1. The key data source was observation of the classroom discourse. All lessons were observed and videotaped. We used a student questionnaire and a teacher questionnaire. Questionnaires data was used as input for student and teacher interviews. Interview data was, together with the students' results on exercises and a summative test, used to interpret observations data.

### **Statistics education**

Shaughnessy (2010) argues that, from the quantitative techniques represented by the secondary school curriculum, statistics may be the most common element of mathematics used after completion of secondary school. In tertiary education, students use statistics during multiple quantitative courses. Professionals use statistics in their working and even in their private lives. Whether Shaughnessy exaggerated a little while stating that statistics is more often used than, for instance, elementary algebra, or not, we agree with him that statistics is for many students very useful. This usefulness is perhaps the most important argument for the firm place statistics nowadays has in the curriculum. The usefulness, together with the applied character of statistics, attributed to the decision to include statistics in the curriculum for mathematics A (the specific variant of secondary mathematics for those students who aim to study in higher economics education or social sciences). In this study we restricted ourselves to the sub-domain of *descriptive* statistics. And as far as learning activities are concerned the focus was on reasoning and sense making, to be called *data literacy* (DL), and on *algorithmic statistical skills* (ASS) (see review of literature below). In the section Review of literature, we will underpin the relevance of this distinction.

### **Mobile classroom networks**

Abrahamson, one of the first researchers in the field of classroom networks, stated that the networked classroom can support real-time formative assessment for teachers (1999). Formative assessment offers a central place for feedback. Roschelle (2003, p. 263), in an overview of research, noted that: "*these systems* (referring to what he earlier calls 'classroom response systems') *enable students to receive much more feedback than normal*", thus considering it an enhancement of feedback possibilities. He continues (2003, p. 268) with "*Students can perceive receiving much more individualised assessment feedback...*". These remarks, made after having observed early practices around classroom networks, suggest that formative assessment, feedback and classroom networks are a quite logical combination. These authors apparently see advantages in the use of a classroom network in order to establish formative assessment for the sake of feedback.

Different terminology is used in reported research to describe more or less the same infrastructure from the perspective of functionality: *classroom response systems* (Fies & Marshall, 2006), *student response systems* (Penuel, Boscardin, Masyn, & Crawford, 2007) or *classroom networks* (Roschelle, Penuel, & Abrahamson, 2004). All of these share the same basic idea of using a wireless network of handheld devices. In this study we utilized graphing calculators as handheld devices, because of the mathematical functionality offered. The network allows teachers to provide mathematical content to the students, to gather students' work on this content, to analyse this work and to provide feedback on it.

### The classroom network in practice

In order to get a concrete idea of classroom activity, we first describe in terms of ICT-facilities what we see in the classroom when using a classroom network (CN). This is illustrated in Figure 2. The functional interaction takes place between the teacher's computer and the students' graphing calculator (GC). All of the students have a GC at hand as is usual in Dutch upper secondary education. Technically, the GCs are in groups of four, connected to a hub. This hub communicates with an access point that in turn communicates with the teacher's computer. On the teacher's computer there is software that is able to analyse the students' work and to represent this analysis in a slide show. Using the data projector and the projector screen, the teacher can make this analysis available for the students.

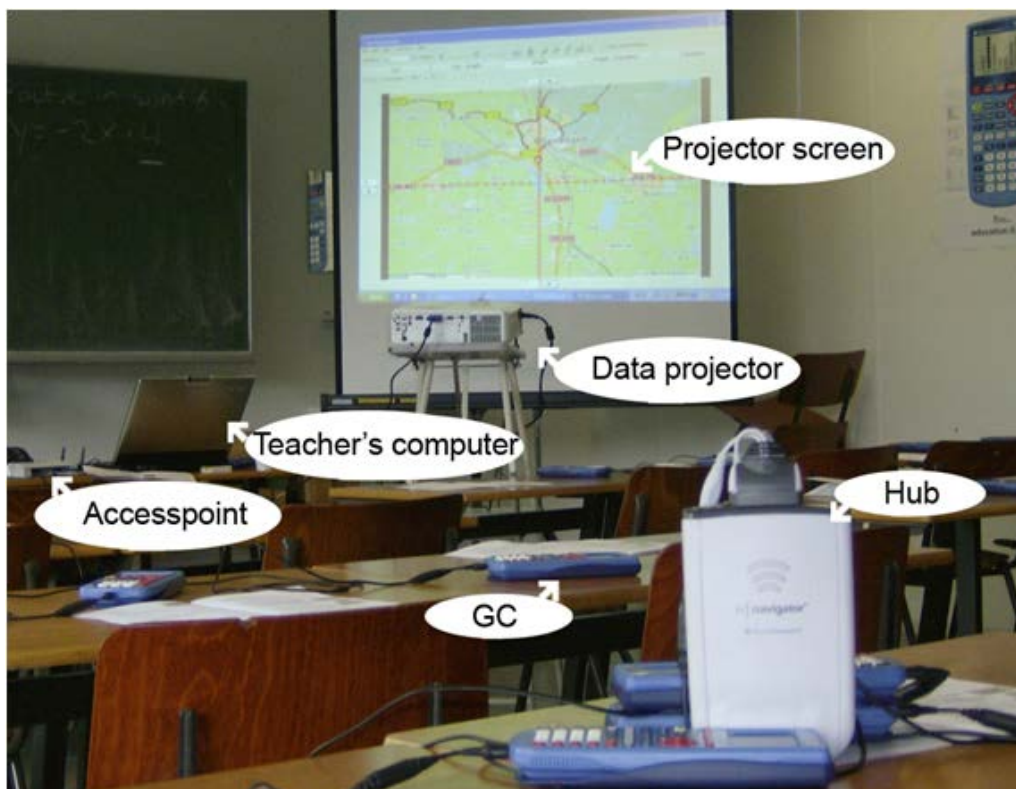


Figure 2: The components of a classroom network in practice

In the last adaption of the network the hubs were replaced by a Wi-Fi cradle for each GC, making the network really wireless.

### Research questions

The main research question was as follows:

*What is the potential of a wireless classroom network in supporting upper secondary statistics teachers with providing feedback?*

Four sub-questions were derived as follows. With respect to the *feasibility* of the chosen approach, we asked ourselves whether the chosen technological configuration (see Figure 2) was adequate for supporting feedback and whether a mathematics teacher was able to utilize this support in order to provide feedback as intended.

Thus, two sub-questions arose from the main research question:

1. *Is technological support by means of the classroom network adequate for the intended feedback in the lessons?* (Conditional question)
2. *Is it possible for a mathematics teacher to implement the prototype in accordance with its intentions?* (Existence question)

With sub-question 2 also the quality of the feedback is investigated, by comparing the realised feedback with the intended feedback. After having distinguished the statistical learning goals, we asked ourselves whether the realised feedback was both on algorithmic statistical skills (ASS) and on data literacy (DL) activities. Therefore, we specified a third sub-question with respect to the general research question:

3. *Is the feedback support of the classroom network equal for ASS and DL?* (Didactical question)

With sub-question 3 we investigate the feedback provided by the network and by the teacher to the students as well as the feedback provided by the network and by the students to the teacher. While realising that teacher behaviour is the first focus of this study, we would like to identify the situations in which feedback was realised as intended and in which situations it was not. Thus, a fourth sub-question emerged:

4. *Which teacher characteristics promoted/hindered the implementation of the classroom network as intended?* (Identification question)

This fourth sub-question is rooted in our sense of the complexity of the intended intervention. A teacher will have to be able to manage a lot of actions simultaneously: the statistics itself and the learning goals, the students' input as collected and rudimentary analysed by the CN, the ICT environment, and the flow of the classroom discourse as initiated by the teacher feedback. A close observation of teacher behaviour should result in data with which this sub-question can be answered.

#### **How has EDR been applied?**

In Figure 3 we depict our study in terms of the well-known ADDIE components (Gustafson & Branch, 2002; Molenda, 2003; Molenda, Pershing, & Reigeluth, 1996): Analysis, Design, Development, Implementation, and Evaluation. Reflection *in-action* and *on action* (Van den Akker & Kuiper, 2008) with respect to the quality of both the intervention and the EDR process were part of each phase.



## 2. Analysis

### Initial study

An initial small-scale intervention study (one teacher, one class, and a prototype different from the one described in this chapter), was conducted with the purpose to identify what can be observed when a wireless classroom network in mathematics education is utilised. For details on this study, we refer to Tolboom (2005). It turned out that teacher feedback on the students' work seemed the pivot for the intensified classroom discourse. The teacher and students indicated that the use of the classroom network was the facilitator of teacher feedback. The results of this initial study motivated us to set up a study into the potentials of a classroom network to support the supply of feedback in statistics education.

### Review of literature

#### **Feedback**

Meta-analyses show that, from the perspective of students' achievement, feedback has a large positive effect (Hattie, 1999; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Marzano, Pickering, & Pollock, 2001). In his synthesis of over 800 meta analyses on learning achievement, Hattie (2009, p. 12), states that "...*the most powerful single influence enhancing achievement is feedback*". Sadler (1989) underpins the importance of feedback by stating that the acquirement of skills needs practicing, and that practicing needs feedback. This has been supported by subsequent research on the role of feedback for improving knowledge and skill acquisition (Azevedo & Bernard, 1995; Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Moreno, 2004; Pridemore & Klein, 1995). This is important, because statistics education inevitably requires skills. Lovett (2001) concluded that feedback was useful to help students improve their ability to select appropriate data analyses, which is specifically interesting for this study, because in the domain of descriptive statistics analysis of data is the main goal. There seems to be a broad consensus that when wanting to improve student achievement, feedback is a major variable to focus on.

Shute (2008) emphasises the interwovenness of feedback and formative assessment and explicitly focuses on the student as a recipient of feedback, in which she differs from Black and Wiliam (1998). The main goal of feedback is to diminish the gap between the learners' factual level of knowledge, skills and beliefs, as shown in learners' work, and the level which is aimed at by the teacher or, more generally, the curriculum. This 'closing the knowledge gap' (Ramaprasad, 1983) is an important example of 'improving learning' as posed by Shute (2008). Following Shute (2008) and Black and Wiliam (1998), the *goal of the feedback* is improving the learning process and result of *the student*.

What about the difference between Shute's (2008) use of 'feedback' and its use by Black and Wiliam (1998)? Who is giving and who is receiving feedback? Shute's definition of formative feedback (2008) does not point out which actor is responsible for giving feedback. Hattie and Timperley (2007) use an 'agent' for the supply of feedback. As possible agents they suggest: teacher, peer, book, parent, self, and experience. Which of these are the most important for this study? When realizing that giving feedback is part of an interaction (Rapp & Goldrick, 2004), feedback can be based on Moore's (1989) identification of three types of instructional interactions: between the *learner* and the *instructor*, *between learners* and between *learners* and *the content* they are trying to master.

While focusing on the feedback aspect of interaction, all of these interactions contain interesting aspects for our study. For the use in this study, and based on Moore (1989), the following feedback types were chosen:

1. *teacher* feedback: given by the teacher on the work of the students;
2. *peer* feedback: from student to student;
3. *curricular* feedback: given by (parts of) the (computerised) curriculum materials to the students.

*Curricular feedback* was restricted to feedback provided through the classroom network. The students' work and behaviour are *at the same time* a source of feedback for the teacher in order to modify instruction. The teacher is in this case also the *receiver* of feedback.

### **Statistics education**

With regard to the goals of statistics education, a distinction can be made between learning activities with a focus on 'data and concepts' and learning activities concentrating on 'recipes'. The former are to be seen as the most important goals of statistics education. They offer the possibility to reason about statistics itself (concepts) and its application (data) in various situations (concepts are transferable and sustainable). On the other hand, there are 'recipes', algorithmic in character, needed to apply statistics in practice. Cobb (1991) advises a focus on 'data and concepts' at the expense of 'fewer theory and recipes'. Nevertheless, working with these 'recipes' (thus: algorithmic activities) is considered to be indispensable for students in order to acquire a sense of where and why 'data and concepts' are needed. Cobb's advice particularly counts for introductory courses in statistics, where intuition should be stressed in order to make the students more receptive to more formal statistical techniques, a possible domain for their subsequent study. Cobb indicates the basic choice when it comes to determining the goals of statistics education. Thus, the learning activities in statistics education should reflect these two sides of statistical activities:

1. reasoning and sense making (Martin, et al., 2009) with and about data (Cobb's 'data and concepts'), to be called *data literacy* (DL);
2. *algorithmic statistical skills* (ASS) (Cobb's recipes).

When comparing both types of knowledge to the characterization by Van Streun (2001), we project ASS on *procedural* knowledge (know *how*; with a little declarative knowledge, know *what*) and DL on *conceptual* knowledge (know *why*).

The category 'Skills' is a rather obvious and traditionally well stressed goal when it comes to statistics education. Gal and Garfield (1997) summarized their own research and that of others on the goals of statistics education. They listed eight goals for statistical education. With respect to 'data literacy', we concentrate in this study on four of the eight goals: 'Understand the purpose and logic of statistical investigations'; 'Develop interpretive skills and statistical literacy'; 'Develop the ability to communicate statistically'; and 'Develop useful statistical dispositions'. The first two are typical for data literacy, the third deserves special attention because the design intervention aims to improve the classroom discourse in statistics classes through teacher feedback on students' work. This is essentially 'communicating statistically'. These dispositions are to be a somewhat implicit part of the intervention, to be made more explicit in the classroom discourse aimed to be induced by teacher feedback. 'Data literacy' is considered to be somewhat less technical than 'statistical literacy'. We consider 'reflection' and 'interpretation' as important elements of 'data literacy'. An emphasis on data and concepts is beneficial for the learning results, as reported by Smith (1998). Moore (1997) also stresses the importance of teaching the statistical concepts. By putting emphasis on statistical concepts, even these students will be able to build up statistical intuition.

This has also been stressed by Watson and colleagues (J.M. Watson, Collis, Callingham, & Moritz, 1995; J. M. Watson, Gal, & Garfield, 1997).

### ***Feedback, statistics education and ICT***

One of the historical applications of ICT in education, Skinner's teaching machine (Skinner, 1958), was focussed, amongst others, on feedback. This promise of ICT never left the educational research radar. There are several aspects of feedback, as distinguished for example by Shute (2008), for which the use of ICT offers advantages. The *specificity of feedback* is interpreted as the level of information presented in feedback messages (Goodman, Wood, & Hendrickx, 2004). Goodman and Wood (2004) found that increasing the specificity of feedback during practice, using a computer for feedback delivery, increasingly guided performers to correct responses, thus profiting from the increased level of specificity. They conclude with respect to ICT that the use of ICT has obvious advantages for providing specific feedback on a frequent basis. In our view, this has to do with the general advantages of ICT (speed and scalability). Davis et al. (2005) reported that ICT-supported feedback can distinguish the level of specificity and that high specificity was especially beneficial for students low in learning goal orientation. It is nowadays more easy to present *complex* feedback in an organised way. When using a hypertext structure, like, for example, on the WWW, it is possible to provide hints in a couple of phases. Nevertheless, the advice to be cautious with feedback complexity still remains. The fact that complex feedback can be easily realised with the support of ICT may never be the first reason to actually design and use complex feedback. For the *addressing* of feedback (to the task level, to the meta-task level, to the personal level) ICT offers no specific advantages. Its general advantages, of velocity or scalability, of course, remain. For the *timing* of feedback, ICT offers obvious advantages when it comes to immediate feedback. The immediateness of *personalised* feedback for a whole classroom cannot be realised without the use of ICT. So when wanting to profit from the benefits of immediate feedback for each individual student (Azevedo & Bernard, 1995; Kulik & Kulik, 1988), it seems inevitable to use ICT for the feedback delivery. Numerous studies have reported learning gains in working this way (Hannafin, Philips, Rieber, & Garhart, 1987; Phillips, Hannafin, & Tripp, 1988).

For the *presentation* of feedback, ICT offers specific possibilities. Think of simulations, animations or serious games. There is nevertheless no research reported in which ICT plays a leading role for the presentation of feedback. Even in the field of serious games there has been no serious research conducted on the possibilities of feedback, although these possibilities may seem promising (Wong, et al., 2007). It appears that researchers are not that interested in the possibilities of ICT for the presentation of feedback. For the *personalisation* of feedback, ICT offers possibilities. The ICT-based learning approach that specifically focuses on personalised feedback is called Intelligent Tutoring Systems (ITS) (Sleeman & Brown, 1982). Despite progress in this area, human teachers have proven so far to be unbeatable in personalising their feedback one-to-one to individual students (Sarrafzadeh, Alexander, Dadgostar, Fan, & Bigdeli, 2008; Streibel, 1986). Anderson et al. (1995, p. 168), as pioneer developers of ITS, gave up competing with human tutors. Lots of subtle attributes of human interaction, like intonation of the voice and body language, are very difficult if not impossible by means of the ICT of today to interpret, let alone to use actively when the feedback situation demands to. Besides that, personalisation of feedback by human means is an intensive and thus expensive process. Personalisation can best be reached in individual interaction, and human tutors are hard to split up in order to be used by more than one student at the same time. This means that for personalisation of feedback, a human tutor needs a lot of time. Computers, on the other hand, are very good at sharing their attention to more than one user. We can conclude that ICT

is not as good in personalising feedback as human teachers. However, ICT can do it very fast and more or less independent from the number of students. Therefore it has a great potential. In our intervention we chose to use both ICT feedback as well as human feedback.

Summarising, ICT has been reported to add value to the timing and personalisation of feedback. It could have a yet unexplored potential for the presentation of feedback. It could also offer its general features of speed and scalability for realising specificity, complexity, and addressing of feedback. In statistics education, there is a very important practical consideration that can be used to advocate the use of ICT. When using sets of real data, as is broadly advocated (Martin, et al., 2009; NCTM, 2005), directing to the importance of data (Cobb, 1991) and the importance of attractiveness for the target group (Garfield & Ahlgren, 1988), students usually have to handle a considerable amount of data (Mills, 2002). This is almost impossible without the support of ICT. Moore (1990) stated that computers and calculators have made more complex analyses on larger data sets possible. Thus, in a way, the use of ICT in statistics education, with goals as are enclosed in our study, is inevitable.

### 3. Design and development

#### Design principles with respect to feedback

The format used for the formulation of design principles has been inspired by the one proposed by Van den Akker (1999) and is formulated as:

If you want to <goal formulation> you are best advised to <procedure formulation> because of <argument>.

With respect to feedback seven design principles were formulated, based on the literature review and practical reasoning, including the following two (for a description of all seven principles, see Tolboom, 2012):

- F1. If you want to provide feedback to students on a task that mainly concerns *procedural and/or declarative* knowledge, you are best advised to provide *immediate* feedback supplied by a *computer*, because this improves the efficacy of the feedback (Azevedo & Bernard, 1995; Corbett & Anderson, 2001; Kulik & Kulik, 1988).
- F2. If you want to provide feedback to students on a task that mainly concerns *conceptual* knowledge, you are best advised to provide *delayed* feedback by *the teacher* after one or some more days because this improves the efficacy of the feedback (Butler, Karpicke, & Roediger III, 2007; Schroth, 1992).

#### Design principles with respect to statistics education

With respect to statistics education nine principles guided the design of the intervention, including the following two (see Tolboom, 2012):

- SE1. If you want to improve the students' conceptual knowledge of statistics, you are best advised to include exercises that aim at developing 'data literacy' by systematically focussing on the students' understanding of the purpose and logic of statistical investigations and their development of reflective and interpretive skills, because this approach appeals more to students having a non-statistical focus (Cobb, 1991; Roback, 2003; Wiberg, 2009).
- SE2. If you want to improve the students' declarative and procedural knowledge of statistics, you are best advised to include exercises that aim at developing 'algorithmic statistical skills' by systematically focussing on the students' skills with respect to practical, well defined statistical procedures, often with a quantitative goal or nature because this



improves the efficacy of the feedback (Azevedo & Bernard, 1995; Corbett & Anderson, 2001; Kulik & Kulik, 1988).

### Feedback matrix for statistics education

When 'immediate feedback' versus 'delayed feedback' are crossed with 'data literacy' versus 'algorithmic statistical skills', the result is a feedback matrix for statistics education as depicted in Table 1.

Table 1: Four feedback types in the feedback matrix for statistics education

Timing of feedback \ Learning goal	Immediate	Delayed
Data literacy	Type I	Type II
Algorithmic statistical skills	Type III	Type IV

For a full description of exercises of types I-IV and examples of each of these feedback types we refer to Tolboom (2012).

### Procedural specification

To illustrate the relationship between the intervention to be implemented, the hypothetical teaching trajectory (HTT) and the realised concrete instruction, we use the movies industry as a metaphor. The prototype can be interpreted as the screenplay upon which the movie is based. The movie itself represents the actual realised instruction in practice. We regard the HTT as the complete script for the movie: it is a director's preview of how she sees what the actors have to say, have to do, where on stage, and how this should look and sound. In this study, the researcher is the director and the teacher is the actor; as in producing a movie, the director uses more than the complete script in order to prepare the actors. Director and actor constantly discuss about how the script is to be translated into a performance before the cameras. We regard this discussion as a vital part of the *procedural specification* (Doyle & Ponder, 1977; McIntyre & Brown, 1979; Van den Akker, 1988).

## 4. Implementation and evaluation during third cycle

After having deployed and revised earlier versions of the prototype of the intervention during the stages C1 (1 teacher, 31 grade 10 students) and C2 (one teacher, 25 grade 10 students), it was implemented in a third stage C3 (6 teachers, 6 grade 10 classes of in total 128 students; each teacher/class was a case; cases were designated as: S1, 25 students; S2a, 23, students; S2b, 17 students; S3, 32 students; S4a, 15 students; S4b, 16 students). S2a and S2b were groups on the same school, with a different teacher. S4a and S4b were groups on the same school, with the same teacher. The intervention in the classroom during each of the stages C1, C2 and C3 took about three weeks, depending on the exact timetable of the school.

In this section the results of the evaluation of the *third prototype* are described. Compared with the evaluation of C1 and C2 this yielded the most specific data. As part of this evaluation a teacher questionnaire was used. In addition, all the teachers were interviewed individually directly after each case study and simultaneously during a group interview after the last case study. From the student perspective, also a questionnaire was administered. After analysis of the results of this questionnaire for each case study, we interviewed three students of each

participating group. We concentrated in these evaluations on: how well was the feedback established compared to the intentions (teachers) and how well was feedback received (students)? In this evaluation, we explicitly identified the role of the CN.

### **Teacher questionnaire and supporting interviews**

This section contains the results of the teacher questionnaire, completed with remarks made during the subsequent teacher interview. Although the questionnaire and interview also investigated experiences with the teaching materials, support and other important contextual issues, we restrict ourselves now to report on the core issue: feedback. The main findings were the following. There was a considerable agreement among the teachers with respect to the potential of a classroom network in order to support feedback in statistics education. This may be remarkable, as it turned out that there were big differences with respect to the resulting classroom discourse, as will be shown in Table 3. The teachers considered the prototype to be suitable for developing DL. They felt better informed about the work of their students. In general, they gave more and more specific feedback. This counts both for ASS as for DL activities. The learning yields were perhaps bigger than in the case of more traditional instruction; on this the teachers were not that sure. They considered about 50% of the lesson time spent on feedback activities supported by the network as optimal.

### **Student questionnaire**

All 128 C3 students completed the questionnaire. The questionnaire consisted of 20 statements about statistics education and feedback supplied by a classroom network. The five statements that were selected the most, were chosen for a statistical analysis. Those five statements were the following:

1. Because the teacher gives feedback on my work in this way, I get *more* feedback.
2. Because the teacher gives feedback on my work in this way, I get *better* feedback.
3. Because the teacher gives feedback on my work in this way, I manage to master *algorithmic statistical skills* better.
4. Because the teacher gives feedback on my work in this way, I manage to master *reasoning about data and calculations* better.
5. I would prefer to contribute to the classroom discussion on the projection screen *anonymously*.

The statements were formulated on a four point Likert scale, referring to a difference with respect to education without feedback through a classroom network (1: I strongly disagree, 2: I disagree, 3: I agree, 4: I strongly agree). Significance was considered at  $\alpha = 0.05$  with  $\alpha^B = \frac{0.05}{5} = 0.01$ ,  $\alpha^B$  being the Bonferroni corrected level of significance. Significant results of this analysis, per case study and with all the students simultaneously (Total), are shown in Table 2.

Table 2: Results of statistical analysis students' questionnaire

Case	Cronbach's $\alpha$	Item	Response	p
S1	0.68	I would prefer to contribute anonymously to the projected students' answers	Disagree	0.008
S2A	0.52	None		
S3	0.25	Because the teacher gives feedback on my work in this way, I get <i>more</i> feedback.	Agree	0.007
S4A	0.57	Because the teacher gives feedback on my work in this way, I get <i>more</i> feedback.	Agree	0.002
S4B	0.78	None		
S2B	0.60	Because the teacher gives feedback on my work in this way, I get <i>better</i> feedback.	Disagree	0.007
Total	0.57	Because the teacher gives feedback on my work in this way, I get <i>more</i> feedback.	Agree	0.006
		I would prefer to contribute anonymously to the projected students' answers	Disagree	0.002

The conclusion is that, in general, the students perceived more feedback on their work. Differentiation between ASS and DL was not significant. Discussing their answers in public was not threatening. The results differ slightly per case study, as does the consistency of the students' responses.

### Student interviews

From each participating class, three students were selected for an interview: a good (1), an average (2) and a weak (3) student with respect to their mathematical competence, as appointed by their teacher. During these individual interviews, the results of the students' questionnaire in the specific case study were used as input. Students in the six participating grade 10 classes were positive about the improvement of the feedback. Usually, they perceived greater, and more specific, feedback, both on ASS as on DL activities, when compared with more traditional lessons. There was not much difference in appreciation of the feedback between the groups, except for the fact that the students in case study S2b were negative about the lessons themselves. Neither a structural difference could be notice in the experiences of the students as seen from their capabilities in mathematics. The students stressed the contribution of collaborative work to their learning. They did not experience this way of working as more threatening when compared to lessons without a classroom network, except for one interviewed student (out of eighteen) with weak mathematics skills.

### Realized feedback

The realised feedback, classified by the feedback coding scheme as described by Tolboom (2012), was expressed in correspondence scores (Tolboom, 2012), based on observable behaviour. This score can vary from 0 to 7, indicating the degree of similarity between the intended curriculum (hypothetical teaching trajectory, HTT) and the realised curriculum (as shown in the video-taped lessons). In Table 3 we present an overview of the mean correspondence scores (with standard deviation and percentage of missing feedback sessions) of the intended and implemented feedback in the six case studies.

Table 3: Correspondence score characteristics of the cases in C3

Case	Mean	SD	Mean_DL	Mean_ASS	M_DL-M_ASS	%-Missing
S1	5.14	1.70	4.89	5.60	-0.71	68.09
S2A	4.40	2.29	3.66	5.71	-2.05	14.89
S3	5.38	1.85	5.34	5.46	-0.12	0.00
S4A	3.60	2.13	3.65	3.44	0.21	31.91
S4B	3.89	2.09	4.11	3.33	0.78	34.04
S2B	2.04	1.70	1.95	2.25	-0.30	59.57

Legend: The columns respectively present: case study label, mean total correspondence score, standard deviation of total correspondence, mean correspondence with respect to data literacy exercises, mean correspondence with respect to algorithmic statistical skill exercises, subtraction of these means and percentage of missing feedback sessions as compared to the HTT.

The very high percentages of missing feedback sessions should be pointed at, as compared to the HTT in the first (S1) and the last (S2b) case study. In the other four case studies this percentage was 34% or lower, so one on three missing, or less. These high percentages occurred as a result of two completely different reasons: in case S1 we encountered severe technical problems, but when the technology was up and running, the teacher managed to implement the curriculum rather close to the intentions. In case S2b the relationship between the group and teacher was problematic. This was discouraging to the teacher to the extent that she could not really implement the intended curriculum.

#### Results per sub-question

This intervention study was carried out because mathematics teachers experienced a curricular overload. The main idea was to improve the quality of contact time through an improvement of teacher feedback. We therefore utilised the possibilities of a classroom network. Teachers and students participating in this study agreed on the fact that during the intervention more feedback was established than during the usual educational setting.

The main research question was operationalized in four sub-questions. Based on the findings presented in Table 3 as well as questionnaire and interview data, those sub-questions can be answered as follows:

1. *Was the technological support by means of the CN adequate for the intended feedback in the lessons?* (Conditional question)

After case S1, the technology was stable, both on the handheld and on the network side. The percentage missing was between 0 and 36 (when not including S2b). Case S3 proved that it was possible to conduct every intended feedback session in the classroom setting.

In cases S4a and S4b, with a percentage missing of 35%, it was mainly time management by the teacher that obstructed utilising the CN more frequently. We nevertheless consider this percentage of 35% as reasonable for classroom practice as roughly two out of three sessions have then been realised. In case S2b, with a percentage missing of 60%, we were faced with such a low motivated group of students that the teacher felt that establishing more feedback sessions was not useful.

2. *Has it been possible for a mathematics teacher to implement the prototype in accordance with the intentions?* (Existence question)

We consider case S3 to be a convincing implementation of the intended intervention. This had a high mean correspondence score, both with respect to ASS (5.46) and DL (5.34). Students and the teacher were equally enthusiastic about the improvement of feedback. All of the feedback sessions were carried out as intended, demonstrating that the technology served the intervention very well. Besides a convincing case study being a *proof of existence* for the goals of the intervention it is noteworthy that in every single case study there were feedback sessions with a convincing correspondence score. This means that every teacher, under the right circumstances, has been able to conduct a feedback session as planned. This is even true for case S2b, with a poor correspondence score (1.95 on DL and 2.25 on ASS), low learning gains and low student commitment, during which there were feedback sessions with a satisfactory correspondence score (5 and 4.5). The interviewed students in this group voiced a preference for an average use of the CN in order to start feedback sessions for 65% of the teaching time. Apparently even in this case, the essential power of feedback supported by a CN emerged. We consider these as *'micro proofs of existence'*: the teacher succeeded in conducting at least one feedback session sufficiently according to the intentions while the students were convinced of the feedback potential. As this relates to case S2b, it suggests that for the other cases the evidence is much stronger.

3. *Was the feedback support of the CN equal for ASS and DL?* (Didactical question)

The support for ASS proved to be better on average, but, with a highly specified HTT, we managed to support the teachers in giving feedback on DL in a satisfactory way. The slightly better support for ASS is shown by the fact that the mean difference in correspondence score between DL and ASS was 0.37 (in the advantage of ASS). We consider this gap, with respect to a variable on a scale from 0 to 7, to be quite small. The 'built in' support of the CN for developing students' DL has to be completed by specific teaching methods and by more directing teacher preparation. For this preparation we used one-to-one instruction before, and a similar evaluation after, each lesson.

The big difference in mean correspondence between feedback on DL and ASS in case study S2a during C3 (2.05) deserves some attention. We noted that the teacher in this case study did not have a strong *functional extraversion*. That is, he was not very focussed on leading the students' learning input during the classroom discourse. This hindered him more considerably in the feedback sessions on DL than on ASS. We presume that this could be because, for a mathematics teacher, discussing 'hard' procedures is easier than 'soft' processes. Discussing DL could be perceived as more vulnerable ('Why nagging when having an answer?') and therefore would take more *functional extraversion* than it takes to discuss ASS. In mathematics education, there is a stronger tradition of focussing on procedures than on concepts and ideas.

4. *Which teacher characteristics promoted/hindered the implementation of the CN as intended?* (Identification question)

The data collected during C3 showed that improving feedback in statistics education by the use of a classroom network was possible. But what was needed to make the step from a successful implementation during two case studies (out of six, like we did in C3) to a successful implementation in further case studies? First, we state that we did not reach 'successive approximation' (Van den Akker, 1999) of our 'intended use of the intervention': case S3 (chronologically the third case) came closer to the intentions than the fourth, fifth and sixth case, despite the fact that we continuously used our experiences in order to prepare the teachers in a better way.

Apparently, there was a teacher influence, a group influence, or an interaction between the teacher and group that was bigger than the influence on the intervention. The little difference in corresponding scores between S4a and S4b (with the same teacher for different groups) suggests that correspondence is more teacher dependent than group dependent. With respect to the teacher, this brings up an interesting question related to our main research question: what are the strong teacher influences that cause this variation in correspondence score?

## 5. Reflection and discussion

### Four conditions for feedback potential

Using the results of C3, we can conclude that there are at least *four conditions* that have to be met before a teacher, trained and supported as we did during C3, in a learning environment that is technically stable, can fully utilise the feedback potential of the classroom network in statistics education.

*First* of all, we observed during case S2B of C3 as well as in C1 there should be a relationship between teacher and group that is based on *sufficient mutual trust*. If this trust is lacking, all education is to fail, however well-resourced the learning environment potential may be. Good education is an intimate process. Feedback and classroom discussion are perhaps the most vulnerable parts of it. Mutual trust is indispensable for making these succeed.

*Secondly*, the teacher has to have deep *conversational skills*, including the attitude (or is it even 'personality'?) to apply them as productively as possible in the classroom discourse. This means that she or he has to be a 'conductor' (Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010) of the classroom discourse, which in this context should be interpreted as 'the spider in the web of the educational process'. In this educational process classroom discourse takes a prominent place and leading it means being able to take up responsibility, especially in a communicative way. A sufficient level of *functional extraversion* is needed in order to be able to take up this responsibility. As a supplier of constructive critical feedback on students' work and when acting as a conductor of classroom discourse, the teacher has a very prominent role in the "classroom theatre". This role he not only has to deserve, he has to demand it. We would not go as far as stating that this concerns the immutable level of the teacher's personality. It is about functional behaviour, which can be acquired. But this is a fairly severe requirement which can make it hard for a considerable part of the population of mathematics teachers to utilise the full potential of a classroom network. Very important was, as we observed during all the case studies, that the teacher was using students' names in order to spread the discourse among the whole group. Using students' names is more confronting, because it is more difficult for students to hide. The teacher therefore has to compensate by creating a safe environment, for example by showing some things of his own, without undermining his position as a leader. He has, as a real conductor, to make his musicians excel in their own way, without losing the collective goal. We especially point at the teacher's timing as a conversational skill. As when conducting musicians playing together, timing is essential for the proper performance of a piece of music, timing is also essential for a teacher in order to optimally implement an intended curriculum (in this case: HTT). In general the teacher's repertoire on formative assessment (Black, Harrison, Lee, Marshall, & Wiliam, 2003; Black & Wiliam, 2009) and dialogic teaching (Alexander, 2008) has to be at a sufficient level.

*Thirdly*, besides these conversational skills, the teacher should have competence in *quickly interpreting students' answers* as he has a greater number of these to handle than without the use of a classroom network. He should be able to make 'statistical sense' of much more student input than before. Due to teacher feedback being needed in the case of new ASS or DL student activity, this input will very often have the form of open answers. In this case, making a rough 'feedback scheme' based on students' answers, as we observed in C3 during case S3, can be very useful in giving feedback the right direction, simultaneously doing justice to the students' input. This capability in interpretation of students' input requires sufficient *subject matter (mathematical) knowledge and pedagogical content knowledge (PCK)* (Marks, 1990). The teacher should have a sufficient level of both knowledge types. This may sound trivial or perhaps even offensive. However, in our view there is no simple mathematics. It takes a deep understanding of concepts, ideas, procedures, strategies and links between different mathematical subdomains to be able to effectively process all of the students' responses on mathematical questions (Even, 1993) in real-time. Having much more information to process, like has been reported in this study, makes this job harder.

*Fourthly*, the teacher should have *skills with respect to ICT*. Using technology, both on the handheld side as well as on the network side, should only result in a low cognitive load so that the teacher is able to concentrate on giving feedback and directing the classroom discourse towards meaningful interaction with respect to statistics. If the technology requires too much attention to be handled successfully, this may lower the flow in a discussion. This technical condition may seem somewhat trivial, but in general the teacher acquisition of ICT skills is not to be underestimated (Hakkarainen, et al., 2001) and the integration of ICT skills for pedagogical use is especially difficult (Hughes, 2005). In recent research this aspect of teacher skills is more and more stressed (Mishra & Koehler, 2006). It takes a sustainable effort to maintain these skills in order to be able to smoothly switch to new tools or to new versions of familiar tools. PCK is nowadays supplemented by technological pedagogical content knowledge (TPCK) (Koehler & Mishra, 2009).

During C3 teachers as well as students considered that the supply of feedback using a classroom network, as perceived during this intervention, has such a high potential that they advise dedicating on average half of the lesson time to this teaching activity. It is noteworthy that even in the case study which was far from a success (S2B) the interviewed students mentioned percentages between 50 and 100. Students experienced more feedback than during education without a classroom network. Teachers reported improved feedback possibilities, with no difference between feedback on algorithmic statistical skills and on data literacy. Teachers reported that there was more discussion on data literacy than usual and that students in general were more engaged in the classroom discourse which in turn was more focused on mathematics. Teachers are a little cautious in reporting positive learning gains. In three cases it is reported, in the other three cases the teacher said they did not know.

### **Generalizability**

We now discuss the generalizability of our studied intervention in terms of 'analytical generalizability' (Yin, 2003). With respect to *external validity*, designated as *transferability* by Guba (1981) in qualitative research like this study, this is mostly a concern of the generalizability of the research findings. We have secured this by precisely describing the dependency of our conclusions with respect to the research context (Barab, Baek, Schatz, Scheckler, & Moore, 2008). Attributes of teachers, students, disciplinary content, and technology were taken into account when interpreting our data.

These can be re-used when extrapolating our findings to other educational contexts (Barab & Kirshner, 2001). Further, by conducting this research in 'everyday classroom practice' we made its results more transferable to other research settings.

We presume, for example, that the main findings of this study are applicable to domains of learning other than just mathematics. In none of the used procedures is there an intrinsic domain-bounded step. Of course, the distinction between data literacy and algorithmic statistical skills is a typical statistical phenomenon. However, we used this distinction as an instance of the more abstract distinction between conceptual and procedural/declarative knowledge. This abstract distinction could be used in order to develop a comparable feedback matrix for another learning domain. The restriction to be made here is that the distinction of conceptual versus declarative-procedural has to be meaningful in this learning domain. We cannot oversee other learning domains, but those rather similar to mathematics, for instance physics, should be able to apply the same methodology in order to get comparable results, as the work of Mazur (2009) seems to indicate.

### **Future research**

We recommend an expansion of this intervention study using the materials and research design we developed. This would preferably be for a longer period, for instance nine weeks. In such a period three chapters of a textbook could be taught and learned. With an expansion like that the 'start bias' that comes with working in a new learning environment could be reduced to an acceptable level. From a research perspective, we especially hope for a further outlining of the coding scheme and the correspondence metric, which we see as the main methodological contributions of this study.

We recommend to conduct this research among substantially more than six teachers, for instance between ten and twenty. We expect that a sample of that size should generate sufficient 'variability' amongst teachers with respect to the teacher dependent *success conditions* we formulated in this study. A study like this should yield enough data for the fine tuning of the prototype. When the intervention is adapted according to the findings of a study as recommended, it would then be appropriate to conduct a quantitative effect study. In the training of the participating teachers, the videos collected and analysed in this study could be very useful, as we can conclude from the high appreciation of the videos shared with the teachers in our study using YouTube. Specific behaviour and critical events in the classroom discourse can be highlighted by using our materials.

It would be very interesting after the first intervention to repeat it three years later, meanwhile letting the teachers optimise their teaching according to the principles we formulated. This should show significantly better results (Adey, 2006).

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## LISTEN TO THE RADIO! A Series of Radio Shows as an Intervention to Connect Managers, Teachers, and Staff in a Change process in a Dutch School Organization

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# 33. Listen to the radio! A series of radio shows as an intervention to connect managers, teachers, and staff in a change process in a Dutch school organization

Tjip de Jong & Suzanne Verdonschot

## Abstract

*This chapter presents the results of a design study in which radio shows were used as an intervention in an innovation process in a school organization. The ambition of three initiators in this school was to start up a process to connect colleagues stronger to their organization and to organize commitment, pride, and a feeling of belonging. They used a monthly radio show as a way to attain this. The question that is central in this chapter is to what extent custom made radio shows can contribute to making the new direction of an organization clear to its employees; and to supporting the actual change process that the employees are expected to undertake. Four design criteria formed the basis for the series of radio shows: 1) Employees as active builders of the change process; 2) Connecting stakes of both change initiators and employees; 3) Linkage between above surface and below surface interventions; 4) Creating depth and scale in the intervention. Based on the content of the shows, the numbers of listeners, the reactions of the employees of the school to the shows, and various interviews, the criteria are assessed in order to answer the research questions. The findings lead to design questions that have been discussed with a panel consisting of 2 experts and 2 stakeholders from the school organization.*

## 1. Introduction to the problem

The context of this research is a school organization for vocational education and adult education (both for professional development and for initial training). In the Netherlands this school is called a 'Regionaal Opleidings Centrum' (ROC). Graduates either enter the labor market or continue in professional higher education. In total, there are 5000 students located at seven locations. Staff consists of about 800 employees (among which around 650 teaching staff and 150 support staff). The management board of this school organization in the Netherlands makes an update of their strategic plan once every four years. This plan presents the vision and the steps that are necessary to take in the upcoming years. This plan is sent out as printed copies to the teachers and supporting staff of the school. The management board noticed that even though they put an effort in printing and distributing the plan, employees take hardly notice, and often do not even read the plan. Their question was whether it was possible to find an attractive format to both disseminate the content of the strategic plan and to activate the employees to actively participate in acting accordingly.

The idea then emerged to use a series of radio shows to inform, and activate the teachers and supporting staff. The idea to choose radio podcasts as a medium originated from an internal brainstorm session. It is not the idea to use a regular radio show but rather to make a series of podcasts that can be downloaded, and one live radio show at the location. Radio was considered to be an interesting medium because of several reasons:

- a) it could help to present the new plans in an active way by making use of interviews with members of the management board;
- b) it could help employees to give meaning to the new plans by inviting them to react and to create in-depth conversations by interviewing them;
- c) it could disseminate actions that people are taking based on this plan by making reports on the spot;
- d) it could help to connect to other organizations and possible partners in the region; it could bring some fun to the whole change process because of the opportunity to listen to each other's favourite music songs.

Both the question of the management board of the school, and the idea of using radio as an intervention, forms the starting point of a design research that was conducted in 2012. The research got shape by experimenting with monthly radio shows, conducting literature research on the topic of organizational change, and by a process that is best characterized as continuous reflection-in-action. The central question that the study aimed to answer is:

*How can a series of radio shows contribute to making the new direction of an organization clear to its employees; and to supporting the actual change process that the employees are expected to undertake?*

## **2. Conceptualization of the study**

The ambition of the school board can be framed as a wish for change. They first developed a clear vision in the strategic plan. In this plan they described their vision for the upcoming years with respect to: 1) content and approach of education; 2) professionalization of teachers and supporting staff; 3) management; 4) the network of organizations and people in the region of this school. They then want to spread this plan among their employees with the purpose that they can adopt the vision and will actively contribute to turn this vision into practical actions.

According to Boonstra (2000), change processes often do not have the results that were initially expected. Drucker argued already in 1993 and more recently that in the last decades society has changed from an industrial economy to a knowledge economy (Drucker, 1993). This has drastically changed working relationships and the way of working in organizations. This also has impact for educational institutes. The ROC is a school organization that educates (young) professionals in this changing society. Precisely because this economy is changing, it is relevant that a ROC school organization have a vision to design education in such a way that it prepares students for this society. Studies and initiatives like KSAVE support this line of thought (see for more detailed information also Unesco 2011, or: EU Recommended key competences).

In many institutes, like vocational training institutes traditional assumptions, based on work in an industrial economy, still prevail. In a knowledge economy however, it is necessary to consider revising these assumptions. This section describes the characteristics of the knowledge economy as opposed to the industrial society we used to be. This framework will help in the next section to come up with concrete criteria that could help to design and experiment with an intervention that could contribute to the change process that has been initiated by the board.

Practices that determined success in the industrial economy, like the replication of products and the focus on productivity, need re-examination in an economy in which the value of knowledge is seen as a major economic resource. In a knowledge economy an organisation's success is more determined by intellectual than by physical resources (Harrison & Kessels, 2004). The success of organisations in a knowledge economy is determined by the extent to which they manage to create new knowledge and apply that new knowledge to the improvement and innovation of their products, services and working processes.

With respect to the organisation structure, it becomes clear that with the rise of the knowledge economy a shift takes place from traditional hierarchical structures of companies, towards new forms of cooperation and organisation that consist of network structures (Huemer, Von Krogh, & Roos, 1998). Indeed, instead of hierarchy as a mechanism to divide and organise the work, networks become the structure in which employees connect to each other in order to do their work. This form of cooperation makes it important that employees choose peers, experts, and like-minded colleagues to work on intriguing and urgent questions that they encounter in their work environment (De Jong, 2010).

In this work environment there is no management layer that holds exclusive responsibility for achieving predetermined goals or results. Instead, employees set, together with their colleagues and managers, their own goals. This freedom to set one's own goals goes together with the responsibility to deliver results, therefore employees are given a lot of autonomy in their work. Intrinsic motivation becomes more important in these kinds of work environments. Intrinsically motivated employees tend to be more vitalized than people who are extrinsically motivated (Nix, Ryan, Manly, & Deci, 1999). Intrinsically motivated teams will persevere when things are getting tough, while others would rather give up (Kessels, 2001; Van Lakerveld, 2005).

Maybe the type of questions that employees encountered in the workplace in an industrial economy did not differ so much from the questions that employees face in a knowledge economy. But the necessity to come up with innovative solutions has grown. Where a single-loop learning process (Argyris & Schön, 1978) could lead to satisfying results in the industrial economy, the necessity to develop the ability to go through double loop learning processes that break the existing thinking pattern, becomes more and more important in a knowledge economy.

In a knowledge economy learning with the intention of improving and innovating is very important (Verdonschot, 2009). Work and learning are not separated - as they were or have been though the industrial economy. The training paradigm has changed into a learning paradigm and the work environment takes on characteristics of a learning environment (Dixon, 1999; Kessels & Van der Werff, 2002).

Finally, the relationship between employees and employers has also changed. Baruch (2004) speaks of the 'old deal' and the 'new deal'. In the old deal employees are loyal and conform themselves to their employer. In return they expect security of employment, and career prospects. In the new deal, employees make long working hours, and take high responsibility. In return they expect reward for performance, and autonomy to do their work.

### **The context of the school organization**

The school organization is located in The Netherlands and provides education in vocational training and adult education. It has seven locations and offers education to more than 5.000 students in seven specific domains. During the last couple of years the management has worked intensively with teachers to develop a new structure and vision to organize learning activities for students. This new practiced based learning is now at the heart of the school organization. At the same time management sees it as an important challenge to connect this vision on learning more personally to the teachers. Management wants to touch “the heart” of every teacher and support him or her in developing innovative and strong learning interventions to enable the professional development of their students.

### **3. Criteria for the design**

Many organisations work on innovation and change processes in order to be successful in the knowledge economy. Although the day-to-day practice in many organisations is marked by characteristics belonging to a knowledge economy, the assumptions that underlie the change efforts often still originate in the way of thinking that was common in the industrial economy. We could, however, develop alternative assumptions, derived around the nature of the knowledge economy, and which might be more effective in realizing innovation. The alternative assumptions that assume how effective change takes place form the criteria on the basis of which the radio shows are designed.

#### **Employees as builders of the change process**

Often, management takes initiative in change processes. They develop, either by themselves, or with help from internal or external consultants, new concepts that need to establish a new way of working. Then, they develop a predefined path for the new change to be implemented and prescribe this way of working to the employees. When employees are not immediately enthusiastic for this way of working, this is called ‘resistance’ and management develops strategies to break through this resistance (Ardon, 2009; Cummings & Worley, 2008). A core point in this assumption is that the initiators of change and the actors are seen as different people. Furthermore, the subjects of the change project are regarded as the ‘receivers’ of this process. They are seen as passive entities who do not change themselves but who need to be managed for change (Ardon, 2009; Homan, 2006). However, research on innovation in knowledge intensive firms has shown that in the end the knowledge workers are the ones who step by step innovate their work (Van Poucke, 2005). Normally, talking about the shift from an industrial towards a knowledge society, is applied to organizations. In this chapter, we apply this to a school organization. Teachers and support staff can be seen as professionals. This means they need to be seen as workers who improve, and from time to time radically innovate their own work (Drucker, 1999). If obedience and loyalty are core values, then it is possible for employees to execute something that is developed by someone else. But when work takes on the characteristics of a learning process, it requires that employees feel closely connected to the change process and that they engage as co-developers. A possible alternative assumption could be to regard all employees as knowledge workers who actively contribute to the change process by taking initiative for action according to the new strategic vision in their day-to-day-work environment (Drucker, 1999; Kessels, 2001). The work environment becomes a ‘hotspot’ for innovation. Gratton (2007) characterizes a hotspot as a place that is full of energy, where employees collaborate, ideas become contagious and new opportunities appear.

### **Connecting the stakes of both change initiators and employees**

In an industrial era it was logical that the board of an organization would set out the lines for a change process, and that employees would follow this up in concrete actions. In a knowledge economy however, this becomes more difficult. In order to develop innovative solutions for intricate questions, it seems necessary to combine the opposite interests that are at stake. Pfeffer (1992) describes two strategies of 'getting things done' that are often used in organizations: hierarchical authority and the development of a strongly shared vision. He says that these strategies, although often pursued, are actually problematic. Using hierarchy as a strategy to get things done implies that the highest in rank decides the goal that is pursued. This does not work because for almost all work cooperation with people who do not fall within one's direct chain of command is necessary. And, a critical question that comes up with respect to this strategy, is: what happens if the person whose orders are being followed, is incorrect? These two problems that result from the use of hierarchy to get things done, are especially true for innovations. First, the innovation practices studied did not consist of hierarchical structures in which one has the power over the others and could determine the central goal. Hierarchy as a governing mechanism does not work in the creation of a new and unknown future (Scharmer, 2007). Second, when innovation is depicted as a process in which the outcome is not known in advance, there is no-one who knows in advance what goal could best be pursued in order to make sure that the right direction is chosen.

Using a shared vision then, as a way to get things done, is also problematic. Pfeffer (1992) states that there is not always enough time to build a completely shared conception of the world. In innovation practices too, the pressure to attain results is often high. Besides, the development of a shared vision brings the risk of groupthink. Groupthink is a pressure to conform to the dominant view of others due to a desire for harmony in a decision and consensus in a decision process. Alternative ideas are not being evaluated anymore. For innovation groupthink may lead to the risk of group members becoming more committed to the status quo of the group than to the innovative performance (Angle, 2000; Tranfield, Parry, Wilson, Smith et al., 1998). The group may jointly become tunnel-visioned and get blind-sided (Van de Ven, Venkataraman, Polley, & Garud, 2000).

The use of individual influence to get things done in organizations is brought up by Pfeffer (1992) as a good alternative for the two aforementioned strategies. In this approach the emphasis is on method rather than structure. The two steps that this approach according to Pfeffer consists of, are having one's own goals clear and examining the points of view of others. This leads to the alternative assumption in which both initiators of the change process, and the employees need to connect their interests.

### **Linkage between above surface and below surface interventions**

For a long time attention to innovation initiatives focused on changing formal procedures, adding or adapting hierarchical structures or creating rules to enforce the desired innovation to occur. But when organizational ambitions are high, emotions and deeper sense making of the professionals within the organization also play a dominant role. Without including these dynamics in innovation projects, the risk is to only create superficial ideas, in which initiatives very quickly disappear when projects are finished or external consultants disappear (see Table 1). An increasingly dominant perspective in innovation interventions is to actively connect the two layers in the project in order to increase the success rate of innovation to occur.

*Table 1: Aspects in change processes that appear above the surface and below the surface (see also Model I and Model II theory in use by: Argyris, Putnam, & McClain Smith, 1985)*

Above the surface	Context and visible structure of the organization; observable rules and procedures of the organization; existing management layers, structures, and work processes. Emphasize rationality, suppress negative associations, task unilaterally.
Surface	The actual change or development intervention in the project.
Below the surface	Deeper emotions such as opinions, beliefs, anger, disbelief, questions, insecurity, etc.

#### **Creating depth and scale in change and its interventions**

An existing change dilemma exists of a continuous tension between the depth of the change process versus the proportion (Vermaak, 2009). Organizational change demands that individuals can take time to work on the topic at hand with colleagues, personally, to change beliefs or ideas and to include new behaviour or attitudes. At the same time organizations can have a big number of employees that need to step into this process. This results in a tension between depth and proportion. The result often is to suppress below surface dynamics with intervention aiming at above surface.

#### **4. The intervention: A series of radio shows**

The intervention that is developed by a design team in collaboration with the school organization comprises a series of radio shows. The sections below describe the way this intervention was designed in order to meet the design criteria. Furthermore the intervention itself is characterized, and the different roles (such as radio-DJ, side-kick etc.) are explained.

##### **Design of radio as an intervention to promote change**

There were nine radio shows (see table 2), each show lasted for about 45 minutes. And was distributed via podcasts on the Internet only available for the staff of the school organization. The composition of the design and development teams for the radio shows was based on the different criteria outlined in the following section.

##### **Employees as active builders of the change process**

The radio team that consisted of both managers, and employees from the department of communication. Furthermore in the radio shows interviews have been carried out with several teachers and supporting staff. Each show also has a different focus or topic, making it possible to invite different people to give input in the show.

##### **Connecting stakes of both initiators and employees**

The radio shows offer the possibility to connect different perspectives during live discussions. Different opinions, ideas and beliefs are included. Also the side-kick of the central DJ has a free role, making it very easy to ask critical questions and stretch the interview in order to link various perspectives.

##### **Linkages between above surface and below surface interventions**

The radio shows try to connect that what happens 'above' and 'below' the surface. The radio shows allow for someone to request a favourite song and at the same time have a good discussion or debate. It has quick changes in the dynamic of the interaction.



Radio also creates a lively atmosphere, you can hear each other and discuss about a specific topic, instead of reading it on your computer.

### ***Creating depth and scale in the intervention***

Radio might have the potential to connect the tension between the two poles: depth in the one hand, and scale at the other hand. Radio as a medium makes it possible to share ideas, outcomes and discussions with a certain depth, because the radio studio offers an intimate atmosphere that allows conversations to come to a deeper level. At the same time the shows are available to a larger audience. People can react, respond and connect on the initiative. Furthermore the timing in radio is different from the timing in regular conversations that one would have in organizations. Normally, you could easily talk with one another for an hour or more, whereas in a radio show, this becomes boring very quickly. The average duration of a conversation on the radio is expressed rather in minutes than in hours. An interview of 10 minutes is actually quite long for a radio item. This means that radio makes it possible to have several in-depth conversations during the course of one show.

### **Description of the radio shows**

The project started with two test shows. This took place in November and December 2011. The shows were cut to a trailer, a short radio fragment of around 2-3 minutes to share with people in the organization. Based on the trailer several radio shows of about one hour each were made. A specific item of the new strategy had a central place during each radioshow. A small editing team (consisting of employees of the school organization and the external consulting company) prepared the show: they selected favourite music of colleagues, prepared and planned interviews, etc. Before the start of the show the radio team prepares the show in the studio. After the show was recorded it was immediately put on the website that was especially created for this purpose. The radio shows were not live broadcasted, but rather have the form of audio-files at a lively website. This website contained the complete audio file to listen to the show, and short descriptions of the guests each show. Furthermore the site contains background information on the shows such as an introduction of the DJ-team. Colleagues (teachers and staff) could download the show from this website. The last show consists of a *live* radio show that is recorded and broadcasted at the location of the school. This is also the day that the academic year is opened and colleagues prepare themselves for the upcoming year. This last show can be listened by anyone, and the idea is by making this a live show that alumni, organizations in the region, students, friends and family of the employees, and other people in the network are invited to participate and listen to this show.

Table 2 shows an overview of the series of shows. Table 3 offers an overview of the items that recur each show. The theme of the June show is 'At home in the region'. Topics in this show comprise an interview with a local account manager from Rabobank who often invites students for internships. Also a teacher who is connected to the learning-to-work program at the Academic Hospital in Amsterdam is invited. The interview aims to understand what kind of impact these internships have on the professional development of students. Also during the show a student and director of the school discuss specific issues.

Table 2: Overview of the themes and timing of the radio shows

Date	Topic in the show	Location
November 2011	Pilot show	Studio in Hilversum
December 2011	Pilot show	Studio in Hilversum
February 2012	"Our education"	Studio in Hilversum
March 2012	"Finances, accommodation and administration"	Studio in Hilversum
April 2012	"Employees in development"	Studio in Hilversum
May 2012	"Focus on the student"	Studio in Hilversum
June 2012	"At home in the region"	Studio in Hilversum
September 2012 <sup>1</sup>	Starting the new school year	Studio in Hilversum
September 2012	Opening of the academic year on location	LIVE at school

Table 3: Recurring parts and items each show

Flow of the show (every show lasts approximately 45 minutes)
Quick dialogue between guests
Jingle of the show
Song requested by a listener or chosen by the DJ's
Listening to voicemails left by listeners
Looking back at previous shows, and focusing on the topic of this show
News and gossip within the organization
Interview with an external or internal guest
Song requested by a listener or chosen by the DJ's
Interview and discussion on the topic
Song requested by a listener or chosen by the DJ's
Reflection on the discussions with DJ team
Song requested by a listener or chosen by the DJ's
Interview and discussion, sometimes with an external guest
Song requested by a listener or chosen by the DJ's
Facts and figures about ROC ID college
Reflection and deducing some conclusions
Final song

### Description of the different roles of the people involved

In this section we describe the different roles in the project. There are four different expert areas: the DJ team, the technician, the editor team and the producer. All actors participated voluntarily.

#### DJ team

This group play a very visible role in the production of each show. They are the directors of the show and determine what is suitable for recording. Four people are part of the DJ team: two central DJs and two sidekicks. The sidekicks were two colleagues of the school organization.

<sup>1</sup> At the time this article was written, the last two shows did not take place yet.

The central DJs make sure the structure of the show is maintained and take responsibility for the interviews. The sidekicks ask critical questions and have a free role during the show that they can use to ask uncommon or triggering questions and to play around.

#### ***The technician***

He or she makes sure the end product of the show is up to standard. The technician mixes in music, makes intro tunes and keeps an eye on the time during the show. The technician also collects the songs, and cuts or edits specific parts in interviews to enhance quality.

#### ***Editor team***

This team consists of two colleagues of the school organization who worked in the communication department. One is related to the department of internal communication, and one works for the department of marketing. They have the responsibility to inform people who participate in the show participants of the radio show in time, making the complete scenario structure of each show, and also collect relevant material for the website of the show.

#### ***Producer***

The producer oversees the complete series of shows. He connects regularly with the initiators of the initiative and developed the questions and content together with the DJ team. He is also responsible for the budget and making sure the website is up to standard so that shows can be downloaded quickly after recording. In this case the producer has also the role of DJ.

### **5. Assessment of the radio show against the four criteria**

In order to learn more about the outcomes of the series of radio shows in relation to its goals the design criteria were used as evaluation criteria for the quality of the radio shows. This section presents the results of the analysis in which several data sources were compared in order to evaluate the success and the impact of the radio project. In order to answer the research questions we have assessed the radio shows against the criteria. Actually, the purpose is to find out the extent to which the shows contributed to the change process. However, we did not evaluate directly the effects of the change process. We looked at it in terms of the way employees were connected to and contributed to the radio shows. The following data sources were used for this:

- Facts on the number of visitors to the website on which the radio show could be downloaded.
- Secondary analysis of the results of an employee satisfaction research that was conducted annually by the school organization.
- Interviews with two members of the DJ-team to learn more about what they see happening within the school organization in terms of participations of staff members. One of them also takes on the role of producer of the show. He is an external consultant <sup>2</sup>.
- Regular informal meetings between the initiators in which they reflected on the radio show as an intervention.

<sup>2</sup> The authors of the article, together with Pepijn Pillen and Pieterjan van Wijngaarden were the inventors of radio as an intervention in organizational change. One of them (Pieterjan van Wijngaarden) facilitated this process at the school organization that is used as a case study in this article. Pieterjan takes on both the role of DJ and the role of producer in this case.

### **Criterion 1. Employees are active builders of the change process**

- For each radio show a group of colleagues is actively preparing the show. This group enlarges gradually during the flow of the shows. Some of the team members are part of the DJ team. The total number of active builders (people who contributed to the making of one or more shows) can be estimated at ten. This is perceived as a small number.
- During the shows a number of interviews are carried out. Within the school, but also outside the school. During the shows, in total 28 people are interviewed, of which 10 external professionals, 16 teachers or colleagues, and 2 students.
- A teacher who contributed to the show said: "Thanks for the nice experience! Great to hear how real this is! Also quite exciting, but the show is fantastic!"

### **Criterion 2. Connecting the stakes of both initiators and employees**

- Producer of the radio show: "A tension in the project is that the project is quickly seen as a communication project instead of a means to facilitate in a change process. Colleagues and managers are used to more or less fixed communication activities that do often not focus on facilitating change, but rather have a marketing or communication purpose. Although the radio shows have the intention to contribute to the first, it is often experienced as the latter. The department of communication is by employees seen as a vehicle of the management directors as a direct platform to inform their employees."
- Member of the DJ team: "After each show we receive positive reactions of employees. They mention that this is something they really need in the organization. It helps them to look forward. Often these reactions come from participants that visited the radio studio or are involved in the preparation phase in some way."
- The topics of each radio show have a strong focus on content. They mainly focus on actual questions from a managerial perspective.
- The employee satisfaction research showed both positive and negative reactions to the show. Negative reactions focus not per se on the content of the show itself, but rather on the teacher's own context. For instance there was a reaction that there is no money for a teacher that wants to organize a party when he retires but that there obviously is budget for a radio show. There are also employees who regard the radio shows as a vehicle for the management team to express their opinion.
- One of the DJs: "I am not sure if people change their behaviour due to the shows. But people who visited the studio have a lot of energy to start working again. That gives trust and fun to continue with the project".
- A member of the board of directors sent an e-mail to the DJ-team: "I have listened with great pleasure to the first radio show of ID on air. Great work for your work and involvement. This is really about our organization! Very cool, nice music and nice conversations. I gave me a lot of energy and I am really looking forward to the next show. And of course the great final: the third Thursday of September".

### **Criterion 3. Linkages between above surface and below surface interventions**

- In each show there is room for listeners who have called to the voicemail to tell a story or to request a song. For instance in one of the shows a teacher requested a song for her students who were on an internship. She wishes them good luck and says she is curious to hear their stories as soon as they've come back. This is a way to also give room to the things that happen below the surface and that are more connected to personal stories. Every show one or two of those phone calls or requests are being received.
- In each show one or two requests or voicemails are being sent in.

- Reactions vary from listeners. Some are very enthusiastic and emphasize the attractiveness to listen to new development regarding their school organization. Others are more negative and have the feeling it is an initiative of management to inform about new decisions.

**Criterion 4. Creating depth and proportion in the intervention**

- Table 4 shows the number of visitors to the radio website.
- It seems as if there is a core group of listeners. They immediately listen when a show is online, respond via e-mail, the website, or twitter.
- The internal employee satisfaction research showed that around 4% of the 800 employees listen to the show. The first show had relatively high listening numbers. The shows after this resulted in declining of listening numbers. The show after this about “the region” resulted in an increase of listeners.

*Table 4: Overview of visitors of the radio website in January, February and March 2012*

<b>Parts of the website</b>	<b>January 2012</b>	<b>February 2012</b>	<b>March 2012</b>
Listeners & downloads	-	798	258
Shows	49	399	153
Reactions	-	114	33
Poll	-	-	4
Trailer of the first show	12	186	36
About the DJs	22	280	35
About the initiative	17	151	31

*Note: The number of hits explains how many times a page was opened. It does not guarantee for instance that in February 2012 798 different colleagues listened to the radio show*

**6. Conclusions and reflection**

The previous section showed the findings in relation to the design criterion. Based on these findings we draw in this section some conclusions and formulate design questions. The findings show that during the radio shows, the number of listeners dropped significantly (see table 4), and all in all a small amount of colleagues participated (around 4%). At the same time the findings give interesting input for future initiatives to connect radio to organizational change projects. The idea is that answers to these design questions can help to further develop radio as an intervention in change processes. The design questions were discussed in a round table conversation that was facilitated by the authors of this article. In this session two participants (one of them is manager and one of them teacher) of the DJ team and two experts in the field of design research and activating organizational interventions took part. Their role was to act as a so-called critical friend. This section presents the conclusions and design questions per criterion. Furthermore it shows the reactions in the round table session to these design questions.

**Criterion 1. Employees are active builders of the change process**

**Conclusion**

It seems that the aim to support active builders within the school organization via a radio show mainly was realized when staff members would be part of the preparation phase of a radio show. The DJ team is enthusiastic about the shows and prepares it every month with dedication. There is also a large group of participants who act as guests and interviewees.

They are often enthusiastic about their contribution and the show and they show their enthusiasm by responding via e-mail, or via other media after the show. There is also a circle of people who contribute to the show by requesting songs or leaving voicemail messages. Then there is another circle that contains employees who only listen to the shows. Outside this circle there is a large group that does not listen nor contribute to the shows. It seems as if the people who actively contribute to the design of the shows are active builders in a change process. They think about the topic, select guests, prepare and do interviews.

***Design question***

The DJ-team and the editorial team actively develop their focus on the processes that are going on in the school. Others contribute less actively, or even only listen to the show. What could be ways to activate more people and invite them as active builders in the change process?

**Criterion 2. Connecting the stakes of both initiators and employees**

***Conclusion***

Reactions to the radio show as a way to get active builders within the school organization appear to be mixed. Some are positive and others are sceptical about the shows. A possible explanation for the sceptical reactions can be that the topics of the radio show seem to be formulated from a managerial perspective instead of from a teacher or staff perspective. At first sight the topics do not relate to urgent work questions, nor do they refer to provocative or exciting topics. This can be a reason for listeners and possible listeners that the shows do not appeal to them because they do not recognize their own questions. Another explanation can be that the shows are experienced as a vehicle from management to 'push a message through'. The communication department, who is one of the main participants and initiators of the show, are seen as an extension from the board of the school. People therefore can easily get the impression that the radio shows are not really a way to curiously collect different views, but rather as a way to 'communicate what has to be done'. Another finding is that sometimes topics actually do serve as a vehicle to connect different interests. For instance the radio show focusing on the region and location of the school. This show attracted more listeners and many perspectives were connected.

***Design question***

In what way can the radio shows both acknowledge the initiative of management, but also include the interest and stakes of teachers and other colleagues?

**Criterion 3. Linkages between above surface and below surface interventions**

***Conclusion***

For listeners to the radio show there is the possibilities to request a song, or to leave a voicemail message. These moments lend themselves to hear a bit more about what happens 'below the surface'. However, in total the amount of people that interacts in this way appears to be limited.

***Design question***

What could be a way to create more 'rumour around the brand' and to influence the informal conversations that teachers and maybe also students have about the questions and emotions related to the change process?

#### **Criterion 4. Creating depth and proportion in the intervention**

##### **Conclusion**

It seems a challenge to at the one hand create a big group of listeners, and on the other hand develop a core group of participants to have in depth conversations that lead to action. The group of people that are in some way contributing to the shows appear to become active listeners. This raises the question if it is possible to connect depth and proportion during a developmental change process in an organization.

##### **Design question**

Radio seemed to be a suitable way to connect both depth and to scale up the change process. However, in practice, this seems not so easy to attain. Are there examples of interventions that managed to combine these two? What can we learn from these examples for the radio shows as an intervention?

##### **Reflections based on the expert consultation**

A number of interesting reflections emerge while discussing the findings of this research with the expert group. We mention three central reflections:

1. The radio initiative is an intervention to invite colleagues into a radio studio and discuss developments about their school organization. The number of listeners over time drops (see Table 4 for instance), and that could imply a legitimacy to stop the intervention, at the same time the colleagues that participate are very enthusiastic. Change initiatives start small, and needs time to grow. The experts came up with the suggestion to bring the radio shows and parts of it to teams within the organizations.
2. It could be interesting to use radio fragments, discussion, etc. as a toolbox of interventions and content to use in team meetings, or management meetings. Such as Dutch "School TV" that made specific shows on educational topics and distributed it to schools.
3. A change process is also about doing things together, to create new meaning. It could be interesting to use radio as a way of capturing these initiatives and sharing them in the school organization. Instead of discussing these developments.

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## Design Research Focusing on the roles of Multiple Stakeholders in the Development of a Professional Development Programme for Early Childhood Teachers

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# 34. Design research focusing on the roles of multiple stakeholders in the development of a professional development programme for early childhood teachers

Hilde Van Houte, Kirsten Devlieger, Jozefien Schaffler, Thomas Remerie, & Ruben Vanderlinde

## Abstract

*In this case study the processes and outcomes of an educational design research project focusing on the creation of a professional development programme for early childhood teachers to foster inquiry-based science education are discussed. Within this project a research model based on the methodology of educational design research was developed and refined. This model is used to discuss the different phases of the research process, the involvement of stakeholders during the whole research project, the role of the project team, and the 'unpredictability' of the project's outcomes. With the assistance of experts in methodology, the project team developed insights into combining diverse forms of formative evaluation and data processing. This chapter also shows how the project team gained expertise in the active and intensive cooperation with a diverse group of stakeholders.*

*One of the key and crucial aspects contributing to the success of the research has been the open and appreciative relationship between stakeholders and members of the project team.*

## 1. Introduction to the problem

### The problem in context

In Flanders, early childhood education is free for children from the age of 2,5 up to the ages of 6. Within this context both literature (e.g. Entiteit Curriculum, 2007) and observations from practice indicate that Flemish early childhood and primary school teachers are too often directing the actions and thinking of their classroom children. As a consequence, young children are not fully encouraged to find creative solutions to problems they experience, or, put differently, to learn to learn in an environment that stimulates inquiry. In this context, young children's skills in solving problems and exploring their environment may be insufficiently encouraged or developed. Inquiry-based learning opportunities and early explorations are important for the general and scientific development of children, as stressed by Johnston (2005) in her book 'Early explorations in science'. Indeed, Laevers (2002) clearly highlights the importance of such experiences at a young age, stating that '*It is not by seeding mathematics that one will harvest better engineers, but by putting them in a firm background of experience on which they can inoculate abstract ideas*'.

In this context, it is interesting to see that researchers are focusing on young children's early explorations and experiences (Siry & Kremer, 2011; Eshach & Fried, 2005; Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland, 2011). For instance, the project group 'Talenterkracht' (Power of talent) in the Netherlands explores the link between the encouragement of inquiry learning and beta-thinking of young children, and how this influences their future choice for beta-sciences (science, maths and technology) (Raijmakers, 2008). The consequence of learning through inquiry is that teachers may have less control over the progress of the activities

and thus need to be creative and innovative. It is particularly important within science subjects that children can learn from their own experiences, although misconceptions must be avoided. It is clear from literature (Kallery & Psillos, 2001; Rohaan, Tacaonis, & Jochems, 2008) that science (and technology) can indeed be taught in a proper manner if teachers possess enough, correct and relevant knowledge to respond to events within a child's environment, to translate complex scientific questions of children into researchable questions, and support children in their development.

In other words, there is a clear need to support teachers in becoming more skilled at fostering an inquisitive attitude, i.e., an attitude that fosters inquiry in their classroom children.

This highlights the need for an effective professional development programme. However, it is necessary to tailor such a programme to the needs of early childhood teachers, and, as such, early childhood teachers should be closely involved in the development of such professional development programmes.

For this context, the 'educational design research' methodology (Plomp & Nieveen, 2009; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006) was the most appropriate method to conduct the study on the development of a professional development programme for early childhood teachers to foster inquiry-based education, dominantly because of the opportunity of involving teachers as co-researchers and different other stakeholders.

### **Research question**

The educational design-based research project presented in this case study is structured around the following research question: "*What are the characteristics of a professional development programme for early childhood teachers to foster and support inquiry-based science education in their classrooms?*"

This research question is further translated into the following sub-questions identified by the project team:

*RQ 1: What are the characteristics of learning environments for young children that foster inquiry and exploration?*

*RQ 2: What are the basic principles of inquiry-based science teaching in early childhood education?*

*RQ 3: What are the main characteristics of professional development programmes for early childhood teachers?*

*RQ 4: What are the needs of early childhood teachers to foster inquiry in their classrooms and beyond?*

These research questions were answered using a range of data collection methods during the analysis phase as well as in the prototyping phase. In this chapter reference is made to each research question by using its corresponding number (rq 1, rq 2, rq 3 and rq 4). To expound the line of reasoning a brief overview of the research actions and their effects on the outcomes is given below.

A review of the literature provided the general aspects of inquiry-based science teaching and learning environments that foster inquiry and exploration (rq 1 and 2). These general characteristics were discussed and fine-tuned in collaboration with practitioners and experts in the field. Observations of teachers with their children inside and outside the schools during the analysing and prototyping phases were necessary to enrich the findings from both the literature and the discussions.

To ascertain the needs of the different participating practitioners (rq 4), the team observed the practitioners during the different try-out sessions in the project, such as the intake session and

other prototype sessions of the professional development programme. After every session the project members used critical reflection to analyse the needs and teaching style of the different teachers in order to adjust the programme. Conversations and digital communication with the practitioners were also analysed in order to gain insight into their reasoning and knowledge. The main characteristics of a professional development programme (rq 3) were ascertained by reviewing the literature and consulting stakeholders during the analysing phase.

Based on these data, sessions of the professional development programme were developed and refined over several micro-cycles of design. The amount of data and the participation of a diverse group of stakeholders resulted in additional outcomes, including a vision, a handbook, educational didactics, an observation guide, an initial teacher education course, a professional development programme, and an educational design model.

### Applied research approach

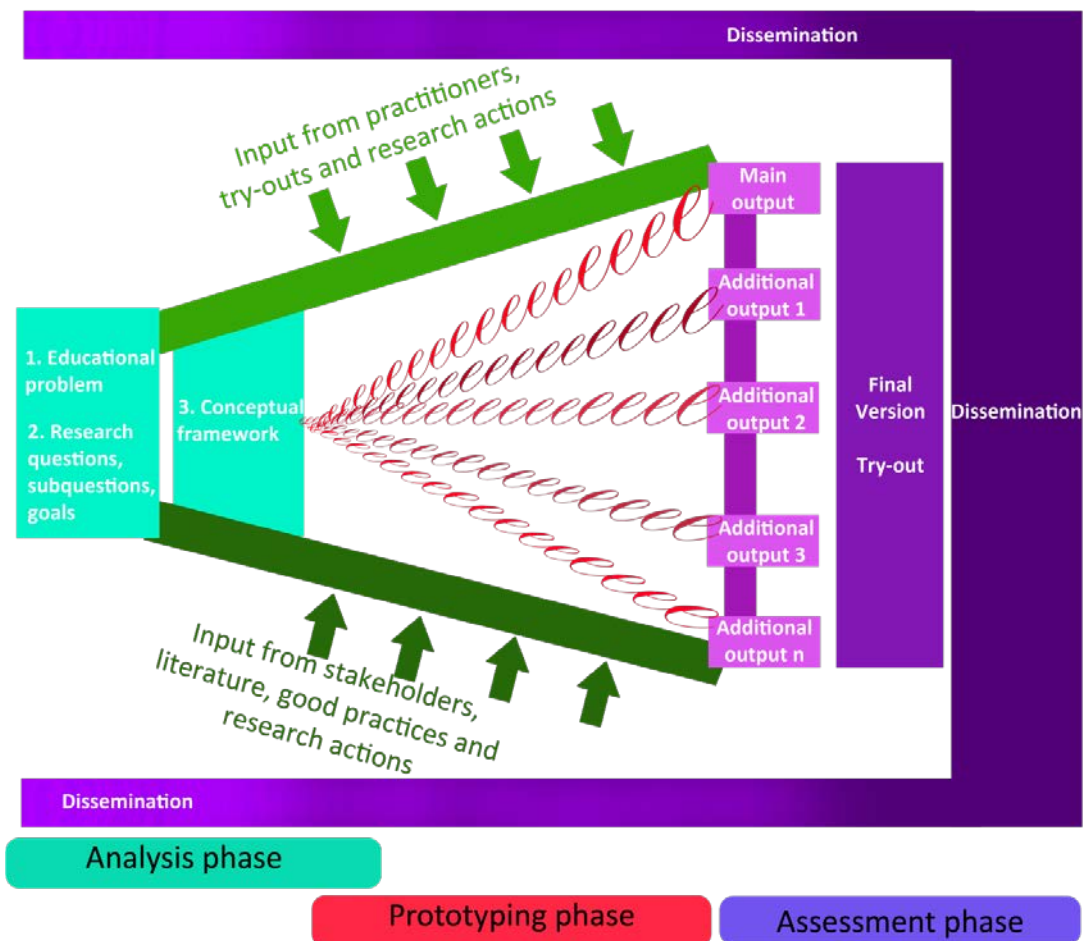


Figure 1: Educational design based model

The main structure of the model presented in Figure 1 is based on literature in educational design research (Plomp & Nieveen, 2009), and was further adapted based on the project teams' experiences in former educational design research projects (Van Houte, Martens, Devlieger, & Ollieuz, 2009; Devlieger, Ollienz, Martens, Schaffler, Mertens, Remerie, & Van Houte, 2010).

The project was divided into three phases: Figure 1 illustrates the three phases of the research projects' educational design research model: (1) a preliminary phase or analysis phase, (2) a development phase or prototyping phase, and (3) an assessment phase. The model shows that the main and additional outputs were all designed using iterative processes during the prototyping phase. During the processes there was input from practitioners and other stakeholders; literature and good practices were selected and try-outs were carried out. As the input and active participation of practitioners was considerably higher, they were placed separately into Figure 1. In this specific project the outputs were: a vision, a handbook, educational didactics, an observation guide, an initial teacher education course, a professional development programme, and an educational design model. The different phases of the model will be further presented and explained in this case study chapter.

During each phase of this educational design research project, several stakeholder groups were highly involved. Figure 2 presents the different stakeholders engaged in the project: practitioners – early childhood teachers (Pr), school leaders (SL), experts in research methodology (EM), teacher educators (TE), experts in education (EE) including educative coordinators in musea or coordinators of educational projects from the government, pedagogical advisors (PA), facilitators for research (FR) including research coaches from the university college, experts in inquiry-based science education (EI), experts in teacher training (ET), and students in teacher training (St). Because of their high involvement in the project, the practitioners - the early childhood teachers - were considered as co-researchers (see Figure 2). This means that practitioners acted as co-designers in the development of the prototypes based on the design principles. At the same time they also had to test, evaluate and refine the prototypes in collaboration with the project team. Since formative research data, regarding aspects such as teachers' style and beliefs, had to be discussed with other stakeholders as well as school leaders, the privacy of the teachers was respected from the start of the project. Figure 2 further illustrates the central position of the core participants - the members of the project team (PT) and the practitioners (Pr) - in the axes. These axes represent the researchers of the project surrounded by the different stakeholders. As illustrated by the connected circles, these groups of stakeholders interacted during several research actions in the analysis and prototyping phase (see below). All participating stakeholders were directly involved in the research, and aware of their active role in the research. The social interactions (face-to-face interactions; exchange of ideas, experiences, and opinions) between these different stakeholders, in or between members of the same of different groups, were substantial and enriched the research. In Table 2 (see below) an overview is presented of the formative research actions and in which the different stakeholders were involved.

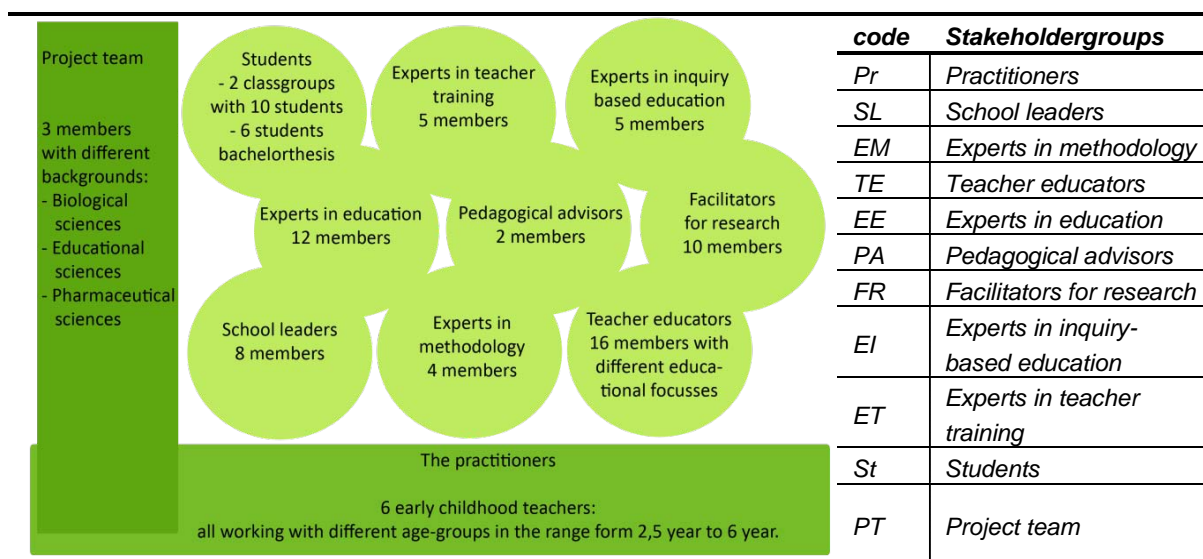


Figure 2: Stakeholders

## 2. Analysis phase

The main goal of the analysis phase was the development of the first version of criteria for the professional development programme. For this purpose a conceptual framework was constructed based on a literature review, an analysis of the practical context of the early childhood teachers, and different consultation rounds with the stakeholders (see Figure 2). The intensive involvement of the same stakeholders in both the analysis and the prototyping phase led to an interaction or overlap between these phases, as illustrated in Figure 1. For example, the analysis of the practical context provided suggestions for the design of the prototypes, and these suggestions were tested by the practitioners (Pr) (illustrated by the line above the conceptual framework in Figure 1).

### Review of relevant literature

Consistent with the research goals, the literature review focused on research on learning environments for young children that foster exploring and inquiry as well as research on characteristics of a professional development programme.

### ***Learning environments for young children that foster inquiry-based science education - rq 1 and rq 2***

Inquiry and inquiry-based education are not easy to define (European Commission, 2007). The use of the concept 'inquiry' in an educational context seems to be characterized by a lack of clarity in terminology (Eurydice, 2011). In a more concrete context of science education, the inquiry-concept refers to at least three distinct categories of activities (Minner, Levy, & Century, 2010). It first refers to what scientists do (e.g., conducting investigations using scientific methods), second, to how students learn (e.g., actively inquiring through thinking and doing in relation to a phenomenon or problem, often mirroring the processes used by scientists), and finally, to a pedagogical approach that teachers may employ (e.g., designing or using curricula that allow for extended investigations). However, these activities are more strongly linked with secondary education than with early childhood education. Furthermore, no suggestions were found concerning the establishment of learning environments for young children.

Exploration and inquiry are also key elements in approaches such as 'Reggio Emilia', experiential education and High Scope (Brouwers, 2010). These approaches are characterized



by an “open framework” approach or a “child-centered approach”. This means that the child has the freedom to think, experience, explore, question and search for answers. The role of the adult is characterized by active listening and observation. In these approaches communication, interaction and a rich environment are essential. In this respect, young children have the opportunity to develop a strong basis for later abstract learning. Children get time to develop an intuitive understanding of the properties of the material world around them, of spatial relations and of quantities (Laevers, 2005).

Broderick and Hong (2005) support these approaches by stating that an inquiry curriculum is often negotiated in the sense that both children and teachers have input into how the curriculum is designed. They speak about ‘inquiry teachers’ who must be open to children’s strengths, challenges, questions, theories, interests and perspectives (Worth & Grollman, 2003).

For this research project, determining a vision on inquiry-based science education in early childhood education, based on the principles of the open framework approaches (active listening, observation, initiative of the child), was identified as one of the key development principles.

### ***Characteristics of professional development programmes – rq 3***

In order to further construct the design principles of a professional development programme, a literature review was conducted to clearly identify the main characteristics of professional development programmes.

Literature on change in education teaches us that professional development should be *long term*, with several short-term, realistic, and manageable goals in mind (Dawson & Suurtamm, 2003). This is confirmed by Selmi (2009), who argues that professional development must be a permanent process that rebuilds the knowledge of the teacher, and fosters curiosity, inquiry and exchange. Teachers must have time and ample opportunities to reflect and discuss their ideas with others (e.g. teachers and experts). Such opportunities are provided in ‘professional learning communities’ as these initiatives encourage sharing, discussion, exchange, and collaboration among its members. Indeed, research on professional development (e.g. Borko, 2004) provides evidence that strong professional learning communities are important contributors to instructional improvement and school reform. According to Borko (2004), the role of the leader or facilitator in these communities is crucial to the success of the professional development programme. Facilitators must be able to establish a community of learners in which inquiry and critical dialogue is valued, and they must structure the learning experiences for that community. Continuous professional development facilitators need to be experts on the content as well as experts in adult and professional learning (Cordingley, Bell, Rundell, & Evans, 2007).

Furthermore, professional development is strongly shaped by the context in which the teacher works (Timperley, 2008; Borko, 2004). This implies that when designing professional learning opportunities, it is important to consider teachers’ prior knowledge of curriculum and assessment and how they view existing practices. The link between teacher learning and pupil learning appears to be another element in designing professional development programmes (Schollaert, 2011). Timperley (2008) argues that professional development cannot be called effective unless it leads to improved pupil outcomes. Davies (2010) also stresses the necessity of full commitment and trust. The author found that learning activities designed to raise engagement and develop teachers’ skills, knowledge, and enthusiasm were: classroom workshops, consultancy, and educational visits.

To conclude, the following characteristics were identified as key elements that need to be considered when designing a professional development programme: a long term and community-based programme, taking into account the prior knowledge and beliefs of teachers,

fostering inquiry and critical dialogue among teachers, considering the teacher educators as facilitators and experts, improved pupil outcomes, and full commitment and trust of all participants.

#### ***Analysis of the practical context***

The analysis of the practical context consisted of two different elements. Teachers and school leaders were screened during an intake session. The teachers' inquiry practices, teaching style and the classroom environment were observed during classroom visits using observation lists and video recall. As mentioned above, the analysis of the practical context provided insight into the needs of the teachers and enriched the findings from the literature.

#### ***Intake sessions – rq 4***

During an intake session teachers and school leaders were screened together in their own school to give the research team the opportunity to closely screen the diversity of the practitioners and the school leaders. Diversity is related to their teaching practices, their learning styles, their motivation to facilitate the research and to act as co-researchers. The project team selected nine schools for intake screening, based on earlier participation in projects or on the recommendation of teacher educators. The screening process included a) an informative talk about the goal of the research, the role of the teachers and school leaders, the conditions of the cooperation, and the possible benefits; and b) an interview with the teachers concerning their classroom practices and with the school leaders concerning the schools' pedagogical project. These interviews provided part of the information about the starting situation and the diversity of the different participants. Only when the teacher agreed to fully engage in the project and the school leader agreed to facilitate the cooperation, could they join in with the practitioner group or the school leader group (see Figure 2). Finally seven schools agreed to participate. The six teachers involved were early childhood teachers from classes with children aged 2,5 to 6 years old.

#### ***Analysis of the practical context using video recall and observation lists – rq 1, 2 and 4***

In order to get acquainted with the teachers' teaching styles, their ideas about inquiry education and teaching, and their perceptions of their teaching practice, all participating teachers and their classroom children were observed during inquiry activities within a predefined subject theme (water, sand or light).

Prior to these observations, in a preliminary group session teachers received instruction about the inquiry activities, background information on the subject themes (water, sand and light), and a box with day-to-day materials relevant for the subject theme. No pedagogical or didactical information was provided in order to not influence the teachers in their preparations and practice.

Each teacher was observed in their own classroom by two researchers: one researcher videotaped the activities, the other one observed the activity using a fixed coding list. Afterwards, the videos were watched and discussed together with the teachers using the coding list. The results were analysed by the researchers and discussed with the participating teachers during a second group session using the videos of the different inquiry activities. Special attention was also given to the needs of each teacher (e.g. information about didactics, information about content, discussions about visions, and reflection on the actions of children). Based on the analysis of the inquiry activities and the teachers' styles, the role of the researchers changed, and they increasingly became coaches, consultants and experts.

### **Consultation of stakeholders**

Stakeholders from every group (see Figure 2) were consulted regarding their expertise on or experiences with inquiry-based education and professional development programmes.

### ***Inquiry-based education – rq 1 and 2***

The advice of experts was invoked by using focus groups in order to translate ‘inquiry-based learning and education’ into education that fosters an inquisitive attitude, and to formulate the research teams’ vision on inquiry-based learning and education. Two focus groups were organized: one group with teacher educators (TE), and another group consisting of pedagogical advisors (PA), research facilitators (FR), experts in teacher training (ET), inquiry-based education (EI), and methodology (EM). The focus group meetings were recorded and important issues concerning inquiry and inquiry-based education, and the role of teachers and learning environments, were extracted and further analysed by the project team. Additional interviews with individual experts were conducted to test and elaborate on these issues. Based on the results of both the discussion groups and the interviews, it became clear that the terms ‘inquiry-based learning’, ‘inquiry-based teaching’ and ‘inquiry-based education’ were very confusing, and different stakeholders had different opinions. However, they all agreed that education has to foster creativity, inquiry, curiosity, exploration, engagement, and conversation. Active learning and more natural learning was found to be important, and education was to be considered more from a holistic point of view.

The findings of the brainstorm group discussions confirmed the necessity of developing a common vision about inquiry learning, inquiry teaching and fostering/developing an inquisitive attitude. In order to be relevant for a broader field of practitioners, teacher educators, and educational advisors, this vision needed to be constructed in collaboration with the participating stakeholders.

### ***Professional development programme fostering inquiry-learning – rq 3***

On the basis of the project team’s experiences in earlier teacher training programmes, interviews with experts specialized in training programmes (e.g. pedagogical advisors (PA)), focused interviews with school leaders, and brainstorm sessions with practitioners (Pr) during the first session, a list of criteria concerning the professional development programme was created. This list was combined with other data to extract the design principles of the professional development programme (see Table 1).

One of the major criteria is that the focus has to be on the development of a curious, inquisitive, reflective and critical attitude. The same philosophy was found in the objectives of a professional training programme about science and technology in the Netherlands (Walma van der Molen & Kuijpers, 2010). This programme assumes that the development of an inquisitive attitude is more important than training in subject knowledge. Furthermore, the six aspects of a ‘scientific’ inquisitive attitude (Van der Rijst, 2007), i.e., wanting to know, understand, criticize, share, achieve and innovate, were also taken into account.

### **Design principles and implications of the analysis phase**

In this analysis phase the necessary requirement of *a complete and strong vision* concerning fostering and developing an inquisitive attitude in young children emerged. The issues extracted from the focused interviews with experts and practitioners in combination with the results of the literature review were used to design important key aspects, from which a first-draft vision text concerning inquiry in early childhood education was created. The vision text was further developed during the prototyping phase (see below). Key aspects of the analysis phase were:

- Young children are natural born inquirers, explorers and researchers.
- Teachers have to start from the child itself by, for example, listening to the children, observing the children, taking the perspective of the child, seeing talents in children.
- Teachers have to become inquirers/researchers themselves.
- It is important to see opportunities in daily (school)life.
- During learning activities:
  - teachers have to encourage creative problem solving: more than one solution is possible for every problem;
  - teachers have to encourage self-regulation;
  - teachers have to provide materials and rich contexts;
  - teachers have to encourage the recording, expression and exchange of aspects such as ideas, results and observations (oral, visual, digital, practical);
  - teachers have to provide time to execute the learning activity.

Based on these key aspects (vision) and on other results from the literature review, the analysis of the practical context, and the consultation of stakeholders, the *design principles of the professional development programme* were developed using the spider web model of van den Akker (2009). The key aspects were seen as the rationale of the programme and the criteria for development were structured following the eight components of van den Akker's model (see Table 1: prototypical design principles).

*Table 1: Prototypical design principles*

<b>Time</b>	<ul style="list-style-type: none"> <li>• The programme has to be longer than one year and professional development does not end after a training programme.</li> <li>• Teachers need time to learn in a natural way and to become inquirers, facilitators and reflective practitioners.</li> </ul>
<b>Location</b>	<ul style="list-style-type: none"> <li>• The programme can be conducted both in and outside the school environment (e.g. outdoor, museum), in a real-classroom context and in each place where inquiry is possible.</li> </ul>
<b>Teacher educator role</b>	<ul style="list-style-type: none"> <li>• The teacher educator should act as a coach, facilitator, expert and consultant. She/he can be consulted during and outside the sessions.</li> <li>• The teacher educator must encourage the teachers to become inquirers themselves; to learn through discussion with other teachers.</li> <li>• The teacher educator should encourage the self-belief of the practitioners.</li> <li>• The teacher educator should enhance the teachers' information skills and familiarity with science so the teacher is able to react to unanticipated events in the child's environment.</li> <li>• The teacher educator should take the teaching style, the beliefs and the teaching practices of the participants into account.</li> </ul>
<b>Learning activities</b>	<ul style="list-style-type: none"> <li>• Theory should be applied as concretely and actively as possible. Teachers must experience the same things children experience so that they can better assess the learning process of children and the time these children need to learn. Teachers have to see and experience the phenomena themselves. Teachers have to experiment, handle and play with the materials the children will be using.</li> <li>• It must be possible for teachers to acquire new ideas and innovative practices.</li> </ul>

	<ul style="list-style-type: none"> <li>• It must be possible for teachers to learn from each other (watch inspiring practices) by conducting classroom visits.</li> <li>• Teachers should learn to listen to and observe children, learn to interact with them and to act as a coach.</li> <li>• Teachers should learn to use children's questions to start and encourage further investigation.</li> <li>• During the programme the development of a learning community as described by Schollaert (2011) should be empowered.</li> </ul>
<b>Content</b>	<ul style="list-style-type: none"> <li>• In the programme there is no need for a specific scientific content, everything in the world around the children and in the environment of school and classroom can be used.</li> </ul>
<b>Assessment</b>	<ul style="list-style-type: none"> <li>• The programme should use observation lists and video recall during individual sessions with teachers.</li> <li>• The programme should use stories of the teachers, drawings made by the children and stories of the children (written down by parents) during group and individual sessions.</li> </ul>
<b>Grouping</b>	<ul style="list-style-type: none"> <li>• In the programme group sessions should alternate with individual sessions.</li> <li>• The groups in the programme should be limited to a maximum of 10 teachers.</li> <li>• In the programme individual sessions in real-classroom contexts with video feedback are needed to reflect on current practices and to combine them with new approaches.</li> <li>• The programme should organize separate sessions with school leaders.</li> </ul>
<b>Materials and resources</b>	<ul style="list-style-type: none"> <li>• The programme should use materials of everyday life (no special equipment for science lessons).</li> <li>• The programme should use multimedia and resources such as web-based resources, articles from educational journals, books, and databases.</li> <li>• The programme should give access to materials and resources fostering inquiry-based learning and exploration.</li> </ul>

### 3. Prototyping phase

As mentioned above, and illustrated in Figure 1, the analysis phase emerged in the prototyping phase. This is due to the fact that all participating stakeholders were already intensively involved in the analysis phase. They also had a strong impact on the research process and the dissemination activities which resulted in several additional outputs (see Figure 1), such as a publication of the common vision on inquiry education (rq 1 and 2), educational didactics combining fantasy, science and inquiry (rq 1 and 2), an observation guide (rq 4), an initial teacher training, and the design-based research model (this chapter). As mentioned above, during the prototyping phase the main and additional outputs were all designed using an iterative process. This iterative process is illustrated in Figure 1 by the micro-cycles of design.

In this project all research steps and formative evaluation actions focused on the main goal “to foster the inquiry learning of young children and their teachers”. The different prototypes were developed, enriched, evaluated and/or refined through formative research based on the following criteria: Prototypes need to be relevant, consistent, practical and effective (Nieveen, 2009). The criteria for developing the different prototypes were evaluated and adjusted through formative evaluation. Additionally, all prototypes should have the potential to foster the inquiry-

based learning of young children. Thus, the main goal of the different formative research methods was to collect relevant information in order to adjust and refine the prototypes on the criteria above. The micro-cycles illustrate the enrichment of these prototypes. Due to these criteria some of the formative research methods appeared to be useful as a tool for teachers, for instance:

- An observation tool was developed by the project team to observe the teachers and their classroom settings. This observation tool was not only used for research purposes; teachers also used the observation tool as a guide to look at their own practices.
- In order to gather feedback on the teachers' practices, teachers asked the parents to write down what children said at home about their classroom activities or class visits. This evaluation method was also used in the different educational didactics to get an idea on what children found the most fascinating.

Table 2: Overview stakeholders, main and additional outputs and research methods

Formative research methods	Reflection	Screening	Brain-storm group	Experts appraisal	Walk-through	Try-out	Critical friends
<b>Stakeholders</b>	PT	PT, Pr	Pr, SL, EM, TE, PA, FR, EI, ET, ST, PT, EE	SL, EM, TE, PA, FR, EI, ET, PT, EE	SL, EM, TE, PA, FR, EI, ET, PT, Pr, EE	Pr, St	EM, TE, PA, EI, FR, ET, Pr, EE
<b>Main and additional outputs</b>							
<b>Vision</b>	PT		Pr, SL, EM, TE, PA, FR, EI, ET, ST, PT, EE	EM, TE, PA, FR, EI, ET, PT, EE		Pr	PA, EI, ET
<b>Handbook</b>	PT		Pr,PT		Pr, EM, TE, PA, FR, EI, ET, PT, EE	Pr	FR, Pr, TE
<b>Educational didactics</b>	PT	Pr, PT	Pr,PT			Pr	Pr, ET
<b>Observation guide</b>	PT	PT	PT			Pr	Pr
<b>Initial teacher education course</b>	PT	PT	TE,PT		TE, PT	St	TE
<b>Professional development programme</b>	PT	PT	Pr,PT	SL, EM, TE, PA, FR, EI, ET, PT, EE	Pr,SL, EM, TE, PA, FR, EI, ET, PT, EE	Pr	PA
<b>The educational design model</b>	PT	PT	PT	SL, EM, TE, PA, FR, EI, ET, PT, EE		Pr	EM
*PT= The project team is only mentioned when the formative research method is done by the project team without other stakeholders.							
Note: See Figure 2 for the meaning of the acronyms							

An overview of the main and additional outputs, the formative research methods, and the different stakeholders involved is presented in Table 2. Sometimes prototypes of different outputs were evaluated together and/or affected each other. For instance, components of the programme were first evaluated by the group of practitioners, and afterwards were integrated into the initial teacher education course and evaluated again together with the student teachers. In the table the code of the stakeholder group was only added to a cell corresponding with an output and a formative research method if they participated in that specific method, for that specific output. When more than one stakeholder group is mentioned in the cell, it doesn't automatically mean they participated in the formative research method together. It also doesn't mean they take in the same role within the formative research method, so it's possible the act in a different manner according to their own expertise.

In addition, the presence of a code in a cell doesn't give any indication of the number of times the formative research method was done. For example, while the project team reflected several times about the vision, i.e., after each formative research action mentioned in the table, the code of the project team is mentioned only once in the cell vision/reflection. As mentioned above, sometimes prototypes of different outputs were evaluated together; however, it could be that they were in a different micro-cycle of design. Because of this complexity there is no chronological overview of the different formative research methods leading to the final outputs in Table 2. Note also that, the length of time needed for these different research actions depended on the necessity for the research action and the specific research context at the give time. In the section below the formative research methods used in this study and presented in Table 2 are explained with examples.

- **Reflection:** discussions about drafts, prototypes, vision and research actions within the project team to select important elements that should be integrated into the outputs or into the research actions.
- **Screening:** checking the prototypes or part of the prototypes by stakeholders based on specific criteria.  
For example: The practitioners (Pr) were given a 5-point checklist to screen their practice in order to generate more insight into the role of the teacher in a learning environment that fosters the inquisitive attitude of young children. Afterwards the checklist was discussed together with the project team, and adjusted and incorporated into the outputs (e.g. the handbook and the initial teacher education course).
- **Brainstorm groups:** sessions with brainstorm activities on subjects linked with the research or on new literature findings (for example, new practices).  
Examples: a session with teacher educators (TE) brainstorming about curriculum adaptation using statements concerning professionalisation of student teachers. There were several brainstorm sessions with the practitioners (Pr) to create new practices based on literature or on ideas of the project team.
- **Expert appraisal:** groups of experts from the same or different expert areas gave feedback on prototypes or parts of prototypes.  
For example: organized sessions with experts from different stakeholder groups (experts in methodology (EM), pedagogical advisors (PA), facilitators for research (FR), experts in inquiry-based education (EI), experts in teacher training (ET)) in order to give feedback on one of the prototypes of the educational design model (Pr).
- **Walkthrough:** going through a prototype with one or several of the stakeholder groups.  
For example: The prototypical professional development plan was presented step by step to the group of school leaders (SL) in order to receive feedback.
- **Try-out:** testing materials and components of the prototypes into the real classroom settings.

For example: During the research project there were several try-outs. The content and type of the try-out depends on the different outputs of the project. For instance, the use of a research book for young children (part of the educational didactics) was tried out by the practitioners (Pr) in their classrooms.

A second example: a real scientific inquiry based session (part of the professional programme and the initial teacher training course) was tried out with the practitioners (Pr) and the student teachers separately.

- **Critical friends:** Experts who gave feedback on specific matters during a consultation in order to improve the process and outputs.

For example: Members of the teacher educators group (TE) were asked to proofread written prototypes of the handbook.

## 4. Assessment phase and yield of the project

### Outputs of the project

This project led to a main output, a professional development programme, and additional outputs: a vision, a handbook, educational didactics, an observation guide, an initial teacher education course, and an educational design model (see Figure 1). Unfortunately, not all outputs could be assessed. For instance, the field test of the complete professional development programme within a larger group of teachers wasn't possible because of the real-life context. This means that a large field test was not possible due to financial and time constraints. However, parts of the professional development programme were assessed in professional development workshops, and the programme as a whole was reviewed critically by the expert groups, the teacher educator group, the practitioner group and the school leader group.

Some of the outputs could, however, be evaluated on a larger scale. The initial teacher education course was field tested twice and is now integrated into the curriculum of a bachelor in education: early childhood education. During the forthcoming years the course will be refined based on feedback of future student teachers.

The vision is implemented in documents of several organizations, such as schools, pedagogical centres, and initial teacher education institutions, proving the value, the usability and the relevance of the vision.

The handbook - based on the vision and the programme - 'Young children, great inquirers. And the teacher?' (Van Houte, Devlieger, & Schaffler, 2012) has been published and gave rise to several other activities (on demand), such as new project proposals, articles, panel debates and workshops. Due to the strong vision and the publication of the handbook, the members of the project team are also seen as experts in the field of inquiry-based education by other university colleges and educational centres.

The effectiveness and value of the project outcomes could be explained by the intensive involvement of all the important stakeholders of the educational field. Their feedback, ideas, and suggestions gave rise to additional outputs and were integrated into the prototypes. From the start of the project an emphasis was also put on dissemination, as illustrated in Figure 1. The participating stakeholders were well positioned to provide the project team with advice concerning the dissemination strategies. The handbook that was developed is, for instance, based on advice of educational advisors and experts in inquiry-based education. This additional output made it possible to create a more effective dissemination strategy, as the stakeholders suggested including the structure and build up of the professional development programme. One of the chapters in the handbook highlights the development and the final version of this professional development programme. This chapter presents concrete advice to trainers and



teacher educators who want to develop a professional development programme on inquiry-based education.

In addition, the stakeholders themselves act as disseminators. Some student teachers involved in the project developed their own workshops, based on sessions in the initial teacher education course. Several of these student teachers integrated the practices into their field experiences and influenced their mentors.

The practitioners involved participate in workshops for teachers and student teachers. Because of their intensive involvement and the objective of the project (i.e., to encourage the inquisitive attitude of the teachers) the practitioners became critical researchers and inquirers. This group has become invaluable to the team for future projects. Thus, practitioners and the project team decided to create a research community in which all parties are involved. This research community provides critical input and advice to several other projects and since its inception, in 2011, meets three times per year. These practitioners have also gained more self-confidence and they have become real inquirers in their own classrooms. This is illustrated by one practitioner:

*"The research project has given my self-confidence a boost, and it has taught me several things: discover, just try out, encourage young children, let them be the initiators of the activities ... it can't go wrong. Experiences of success give you the taste to do more, that's for sure."*  
(Participating teacher)

#### **Reflection: lessons learned**

The intensive involvement and open-minded participation of the different stakeholders and the project team formed a dynamic research process which resulted in the creation of important new developments. In this section, emphasis is placed on the professional development programme, the project team, the practitioners as co-researchers, and the unpredictability of the project outcomes.

#### ***General design principles of a professional development programme fostering an inquisitive attitude***

This project shows that a real inquiry-based session with teachers is a crucial component in a professional development programme that seeks to develop and encourage the inquisitive attitude of teachers. In addition, video recall was proven to be very effective in developing the curious, reflective and critical attitude.

During each session of a professional development programme the coach has to take the perspective of the teacher and has to focus on the learner-centred approach. Therefore the coach should be a facilitator, inquirer and important role model for the teachers.

As shown in this project, professional development can only be effective if school leaders are involved and have a substantial role in the programme.

Designers of professional development programmes also have to take in account some practical issues, such as rush periods during the school year and making teachers class-free.

#### ***Participation of co-researchers***

*"I would participate again, simply because I find it interesting to work with other like-minded teachers, on a vision...I think the coaching was approached very professionally, so that I always got new ideas to get started in the classroom. I found the exchange of ideas in practice with other people (whom I otherwise wouldn't meet) very pleasant, informative and feasible."*  
(Participating teacher)

This project clearly shows that in educational design research the practitioners, as co-researchers, see their active participation as professional development. This is an interesting conclusion for teacher programme designers.

They also felt the need to continue the process in a similar way. Hence, a community was created with the teachers and school leaders, as mentioned above. The active participation of the teachers in the community is facilitated by the project team. Student teachers replace teachers in their classrooms during community sessions. The latter could be an interesting solution for other educational design researchers.

### ***The role of the project team***

This study highlights some dilemmas of educational design research for researchers. Since the participating practitioners saw this educational design research project as professional development, the members of the project team inevitably had a double role. They were educational design researchers as well as teacher educators. This double role is characterized by finding a difficult balance between expert in design research and expert as facilitator within different school areas. As described by Schollaert (2011), the project members had to link the new developments in the project with current practice, make use of experiential learning, promote reflection, support practitioner research, use a diversity of learning approaches, take into account the participants' emotions, take into account group dynamics, model desirable behaviour, and focus on content and process alike. This was a very intense and demanding process.

On the other hand, the project team had their own goals, extracting criteria for the development of the professional development programme for early childhood teachers to foster inquiry-based science education. This meant they had to collect data and therefore encourage the practitioners in their co-research role.

To realize this balance, practitioners and researchers have to be equal partners, discussing their specific needs and goals, starting from a mutual respect for each other's goals. Thus, educational design research is also about respecting each other and appreciating the expertise and personality of each participant. This project shows that finding a balance is also facilitated by a multidisciplinary and multi-talented project team. Educational design research makes it possible to use these different disciplines and talents, but on the other hand it also requires them to accelerate the research process, deepen the reflective process, foster creativity, and create a positive flow.

The project generated a lot of data and forced the project team to give priority to realistic processing. Therefore the criteria mentioned in the prototyping phase were used as guidelines to adjust and take important decisions concerning these data. This required profound reflection by the project team after each formative research action.

### ***The unpredictability of outcomes of the project***

In this particular project, educational design research was experienced as exciting and unpredictable. The project team noticed changes in the project goals and outcomes, and therefore could conclude that carrying out educational design research is a step into the unknown over and over again. They had to be open for solutions and suggestions they couldn't predict at the start of the project, due to the involvement of several stakeholders with different ideas and expertise.

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## Science in the Irish Transition Year: an Opportunity to Change the Way Science is Taught

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# 35. Science in the Irish transition year: An opportunity to change the way science is taught

Sarah Hayes, Peter Childs & Anne O'Dwyer

## Abstract

*One unique aspect of second-level education in Ireland is the Transition Year. This is an optional year between the junior and senior cycles. Taking the Transition Year is optional, for both schools and students, and around 75% of schools offer it and just over 50% of students in the age cohort take it. There is no defined curriculum and no state examination, and schools and individual teachers are allowed to teach what and how they like, within certain broad guidelines. Science is not compulsory but plays an important role in the year and is usually included. However, Irish Science teachers are not well equipped to use this opportunity to innovate or to design their own courses and teaching materials. The TY Science project has been developed to provide relevant, STS-focused Science modules for use in the Transition Year. A unique feature of the project is that the materials have been developed by final year trainee Science teachers, in cooperation with Science educators and practising Science teachers. The materials have been trialled in schools on a small scale, evaluated by feedback from students and teachers, and then revised and made available to teachers. Since 2003, over 10 modules have been developed in a range of Science topics. The TY Science modules have been well received by teachers and have been widely used. This project is a good example of curriculum development, based on a design research framework, which involves trainee Science teachers, Science educators and Science teachers in a collaborative partnership to tackle a perceived need.*

## 1. Introduction to the problem

In order to understand the special case of the Irish Transition Year, it is important to give a brief introduction to the Irish education system, and the place of the Transition Year within this system. This chapter utilises a two part approach: these detail both issues surrounding Science in the Transition Year and a novel method which has been utilised to overcome some of these issues on a small scale. Mertens (1998, p. 51) notes that a theoretical framework should not be static, but dynamic, evolving with the study; the method which has been chosen in this project was done so because it was deemed 'fit for purpose' (Cohen, Manion, & Morrison, 2007, p. 78). A dual and complementary approach was taken, utilising both Design Research (Reeves et al., 2005) and the framework of Participatory Action Research (Eilks & Ralle, 2002). Design research was deemed appropriate as "by its character it aims to be practically relevant", meeting the complex needs and providing a practical solution for something as diverse and complex as the Transition Year Science Programme (Plomp, 2009).

### The Irish education system

The Irish Education System consists of three basic levels: primary (first level) education, secondary (second level, post-primary) education and higher education (third level). Education at all of these levels is free for all, although there is a sizable registration fee for third level, and

is provided by the state. Private schools play a very small part in the Irish system. Education is compulsory for all children from the age of 6–16, or until the child has completed at least three years of second level education. Ireland is unusual in Europe, in that a large number of post-primary schools are still single-sex schools, meaning that the gender intake of a school is either single-sex male or female, and also in that the majority of schools are still controlled by religious bodies. Co-educational schooling has been a more recent trend. There are three main types of post-primary schools: secondary (52%), vocational (35%) and community/comprehensive (13%). In Ireland the term 'secondary' refers to a particular type of partly-private second level school. The Transition Year is offered to all post-primary schools, after the junior cycle, and before the senior cycle, it is then up to the school whether they choose to offer it to their pupils. Figure 1 gives a more detailed outline of the Irish education system.

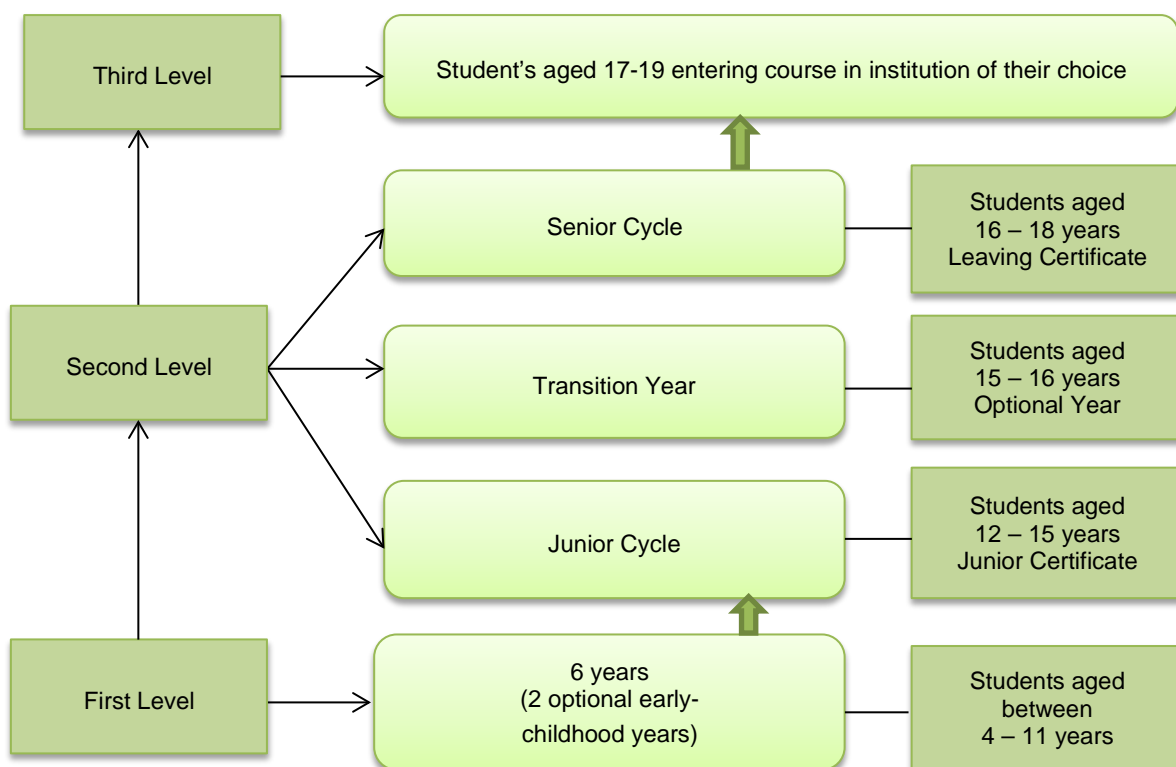


Figure 1: The structure of the Irish education system (Hayes, 2011)

The junior cycle culminates in the Junior Certificate examination, where Science is examined as a single combined subject. The assessment includes 35% for practical work. The senior cycle offers five Science subjects – Agricultural Science, Biology, Chemistry, Physics, and Physics with Chemistry (a combined subject). These are examined at the end in the Leaving Certificate examination. None of these Science subjects include any assessment of practical work. Science is not compulsory in the junior or senior cycle. A recent survey of Science education in Ireland, with particular reference to Chemistry, can be found in (Childs 2010, p. 310-332) and the most recent compilation of Science statistics can be found in Childs (2012). In the remainder of this chapter we describe the Transition Year (TY) in further detail, the role of Science within this year, and the 'TY Science' project, which has developed appropriate teaching materials for the Transition Year.

## 2. The Transition Year

### The structure of the Transition Year

The Transition Year is an optional one year programme offered to students after they have completed their Junior Certificate, but before they enter the next examinable stage (5th and 6th Year - Leaving Certificate cycle) of their second level education. The mission of Transition Year is "To promote the personal, social, educational and vocational development of students and to prepare them for their role as autonomous, participative, and responsible members of society" (Department of Education, 1993, p. 1). The year is designed to act as a bridging year between the two examinable cycles of second level education. It was designed to enable students to move away from the highly structured, formally examinable education programme which prevails throughout the Irish schools system (Smyth et al. 2007, Jeffers 2011). The Transition Year programme itself varies from school to school. Each school has the autonomy to choose and design their own timetable and programme, in order to cater for the needs of their own students. This must be done in accordance with the TY guidelines and will vary depending on each school's resources. However, a whole school approach is recommended (Department of Education, 1993; ScoilNet, 1999; Smyth, Byrne, & Hannan, 2004; Hayes, 2011). The Transition Year, given its optional nature, is not provided equally to students among Irish schools. It is not offered by all schools and if offered, students do not have to take it in many schools. Smyth, Byrne, & Hannan (2004) and Hayes (2011) have found provision of the year varies dramatically across school types and school gender intakes. Schools also differ in whether they offer the programme as an option to their students, or whether it is compulsory. Co-educational secondary schools are more likely to offer the programme on a compulsory basis than other schools. In addition, where small schools offer the year they are also more likely to make it compulsory, as they may not have adequate facilities or staffing to do otherwise, since a compulsory Transition Year makes it a viable year in small schools. Currently uptake of the Transition Year has increased dramatically in comparison with the initial figures (30% of students) when the programme was first mainstreamed (Smyth et al., 2004; Jeffers, 2008), and is now offered in just over three-quarters of schools and taken by just over half of the age cohort (see Table 1).

Table 1: Current uptake of the Transition Year Programme

Year	Number of schools offering the Transition Year	Percentage of students taking the Transition Year
2006-07	524 (71.3%)	46.7%
2007-08	540 (73.7%)	47.1%
2008-09	528 (73.3%)	50.6%
2009-10	552 (76.0%)	53.3%

The figures shown in Table 1 indicate the total number and the percentage of schools offering and the percentage of students taking the Transition Year Programme. These figures show that a significant portion of students are opting for the Transition Year Programme. However, it remains an optional programme, both for the school and typically for the student also. The Transition Year is governed by a set of guidelines, which were laid down by the Department of Education in 1993, and have remained unchanged ever since. These guidelines (1993, p. 4) outline the general aims of the year, which are:

- “Education for maturity with the emphasis on personal development including social awareness and increased social competence.
- The promotion of general, technical and academic skills with an emphasis on interdisciplinary and self-directed learning.
- Education through experience of adult and working life as a basis for personal development and maturity.”

One of the main aims of the Transition Year programme is to produce more self-directed learners, “through the development of general, technical and academic skills” (Department of Education, 1993). The Transition Year Guidelines state that an emphasis on the promotion of personal development and maturity for the student, and maturity through the development of skills and experiences, will help create self-directed learners. Transition Year therefore is designed to provide:

“.. a bridge to enable students to make the transition from Junior to Senior cycle. It encourages personal and social development and recognises the need for students to grow in independence.” (Department of Education, 1993, p. 3)

#### **The Transition Year curriculum**

The Transition Year does not have a curriculum *per se*, but the Second Level Support Service, a body set up by the Irish Government’s Department of Education and Skills, developed the ‘onion model’, shown in Figure 2 below, as a guide for schools offering the Programme.

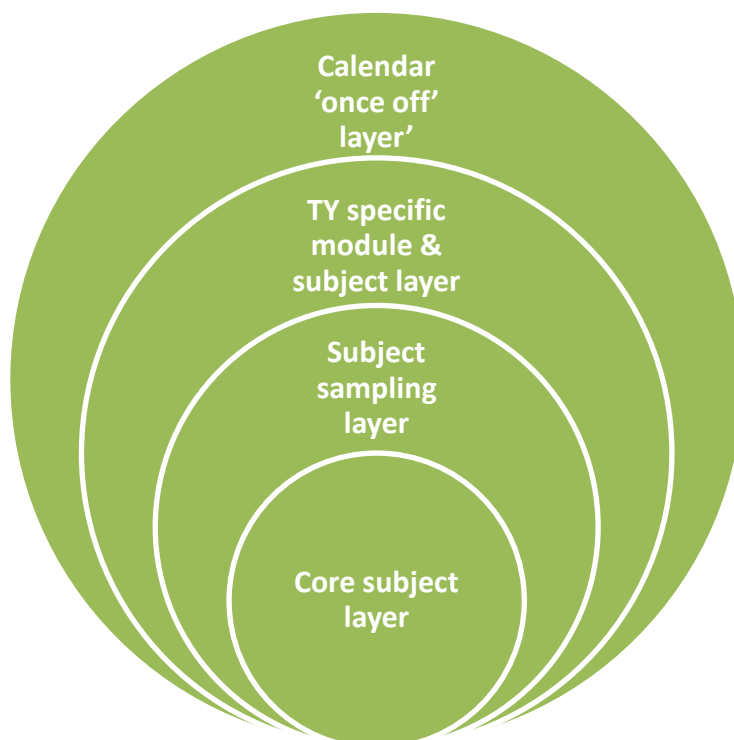


Figure 2: The 'onion model' (Second Level Support Service, 2006)

The 'onion model' indicates the main areas of the Transition Year course: the four areas are the Core Subject layer, the subject sampling layer, the TY specific module and subject layer, and the Calendar - 'once-off' layer. The core layer includes subjects such as English, Irish, Mathematics, Physical Education and Religion. Science may be offered in either the subject sampling layer, with other subjects such as Spanish, Business Studies etc., or as a modular programme in the TY specific module and subject layer. The Calendar layer is designed for once-off events, such as field trips, work experience, outreach and visiting speakers. Unfortunately, as in the Junior Cycle and Senior Cycle, Science is not a core subject and it is entirely up to the school whether or not to offer it or how much to offer. This sampling layer is for subjects that students may wish to try before making the choice whether to study them for senior cycle.

### **Benefits of the Transition Year**

Several studies have indicated that the Transition Year has many benefits to offer students (Department of Education, 1996; Millar & Kelly, 1999; Smith & Matthews, 2000; Jeffers, 2002; Smyth et al., 2004; Jeffers, 2007a, 2007b, 2008, 2011). These benefits are summarised below. They are varied, and are mostly to do with the greater maturity that students gain from undertaking the Transition Year. The main benefits of the Transition Year (Hayes, 2011, p. 45) are:

- Maturity.
- Psychosocial development.
- More likely to continue on in higher education.
- More likely to retain subjects at honours level.
- More educationally adventurous.
- Higher Leaving Certificate grades.
- More likely to take up new subjects.

## **3. Science in the Transition Year**

### **The place of Science**

"Transition Year is an opportunity for students to become familiar with a broad range of Science activities. Students should be encouraged to study areas of Science not heretofore encountered." (Department of Education, 1993, p. 27)

The freedom of the Transition Year offers teachers the opportunity to contextualise science, in terms of its role in students' life and society, emphasising a Science and Technology in Society (STS) approach. This STS focus has been found to be beneficial to students in their learning of Science, enhancing their overall experience of the subject (Gilbert, 2006; Feierabend & Eilks, 2011) and their perceptions of science and science teachers, and narrowing somewhat the gender gap in terms of interest in science (Smith & Matthews, 2000). Transition Year science offers an opportunity for students to choose or sample various subjects in order to make informed decisions about their subject choice at senior cycle. The Association of Secondary Teachers in Ireland (ASTI) believe that the Transition Year should aim to develop students' "scientific skills and to promote a greater awareness of the role of Science in their lives" (Association of Secondary Teachers Ireland, 1992, p. 16).

Smith and Matthews (2000) note that "... the scope of the syllabuses at Junior Certificate and Leaving Certificate are narrow, being largely concerned with matters internal to science rather than to the role of Science (and technology) in society" The opportunity provided to teachers by

the Transition Year could be a crucial factor in the development of scientifically-literate citizens, the promotion of positive attitudes towards science and interest in and uptake of science, if it were properly utilised.

In the Transition Year, schools vary in what they offer as a science programme, that is, they allow students to sample different subjects in different manners and there is no uniform pattern. Generally Transition Year schools either offer a course in one or more of the sciences offered at senior cycle (physics, chemistry, biology, and agricultural science) or they offer a general science course, similar to the Junior Certificate one. The most common courses being offered are in physics, chemistry and biology, the main senior cycle science subjects.

### **The role of Science in Transition Year**

Transition Year science, with the freedom and autonomy it offers, provides a broad opportunity to realise many of the goals of Science Education in the Irish context. In particular, there is the opportunity to offer an innovative science curriculum focusing on developing an understanding of science in real-life contexts, i.e. an STS focus. This is a realistic and manageable objective within the Transition Year Programme and is in accordance with the Transition Year Guidelines, which state that a “Transition Year Science module should explore the links between Science and society” (Department of Education, 1993). This allows students, who might have otherwise not appreciated Science in the junior cycle, to become excited and enthused by it. A good Science programme in Transition Year can lay the foundations for a rich and rewarding scientific career for many students (Hayes, 2011). Transition Year is not part of the Leaving Certificate cycle and time is not supposed to be spent on covering Leaving Certificate material. However, it may augment the Leaving Certificate syllabus, as well as building upon Junior Cycle material. The year is a unique opportunity to provide students with a balanced and stimulating exposure to the Sciences (Department of Education and Science, 2002).

Developing and extending the ways in which Science is taught is also one of the goals of the Transition Year programme, as the guidelines state: “A key feature of Transition Year should be the use of a wide range of teaching/learning methodologies and situations” (Department of Education, 1993). As an innovative and optional year in the second level school cycle, it provides the chance to produce a science course which will stimulate and motivate students, produce scientifically-competent citizens and engage students with science as a future career.

### **Research into Science in the Transition Year**

There have been relatively few research studies in the area of Transition Year science, particularly considering that the Programme has been in place since the mid-nineteen seventies. However, those studies that have been conducted have been primarily intervention type studies, aimed at improving students’ attitudes and uptake patterns in science (Smith, 1998; Smith & Matthews, 2000; Matthews, 2010). In addition, certain studies like The Relevance of Science Education (ROSE) project, are of particular interest, as they were conducted with Transition Year science students (Sjøberg & Schreiner, 2010; Matthews, 2007). While all of these studies have been informative and have given an insight into Transition Year teachers’ and students’ attitudes towards science, they have not provided a full or clear picture of how science is taught or valued within the year. A more recent study by Hayes (2011) took a detailed look at the place of science in this year, from the perspective of the students, teachers and schools. Results from this study (Hayes, 2011) indicate that overall, the Transition Year succeeds in being an important and engaging school year for students, teachers and schools. Science is viewed as an integral component of the year, with a high value attached to it, but practices used within Science provision, teaching and learning, illustrate a resistance to change

even when the curriculum content is fresh and different. Teachers find it very difficult to adopt a new teaching style, different to that used in their normal science classes. Students enjoy the subject, and positive experiences of the subject in the year can lead to improved attitudes and uptake of the subjects for senior cycle. Both teachers and co-ordinators hold science in high esteem, but as Jeffers (Jeffers, 2007b, 2008, 2011) notes in much of his work on the Transition Year, there is a problem of both 'innovation and resistance' within the year as a whole, and within science provision in the year.

The Transition Year has an impact on the whole school, and its effect permeates throughout the school's culture and ethos. Planning is the key to a successful Transition Year and a Transition Year science programme; this works best as a whole-school and whole Science department approach. Science is considered by nearly all Transition Year Co-ordinators, science teachers, students and parents to be a 'vital', 'essential' and 'important' element of the Transition Year Programme. The subject is held in high regard among science teachers and Transition Year Co-ordinators, though many teachers struggle to develop their own curriculum for the subject, and end up drawing from the Leaving Certificate science syllabi. This is a common problem experienced by all science teachers, despite their subject speciality, or length of time teaching, although it is slightly less of an issue among those with a background in the Physical Sciences. The key factor behind this is, based on our findings, are a lack of teacher preparedness to make full use of the opportunity, both through pre-service training, and in the availability of in-service training in subject specific areas of Transition Year science (Hayes, 2011).

#### **4. The background to the 'TY Science' project**

##### **Rationale for the 'TY Science' project**

The Transition Year (TY) in schools has undergone what Jeffers (2011) describes as 'domestication', which he defines as schools adapting and shaping their Transition Year Programme in order to suit their own needs, and integrate it into their policies and practices, often "tending to downplay or even omit aspects of TY that are particularly challenging." (Jeffers, 2011, p. 66) and this attitude pervades Science within the year as well (Hayes, 2011). Science in the Transition Year is in a state of continual flux, with no clear framework, and teachers appear to be undecided about what it should encompass and what aspects of the year to emphasise. This is partly due to the ambiguity of the guidelines (Department of Education, 1993), which, while explicitly stating on one hand that the Transition Year is 'NOT' a part of the Leaving Certificate programme, and teachers' should not teach Leaving Certificate material, then also states that the Transition Year does not need to exclude Leaving Certificate material, but that the Leaving Certificate material should be chosen to "augment the Leaving Certificate experience, laying a solid foundation for Leaving Certificate studies" (p. 5). It is easily seen how teachers and schools receive mixed messages from this ambiguity, and this has led to a majority (~66%) of Science teachers to teach from the Leaving Certificate Science courses in the year (Hayes, 2011). It has become the 'norm' to teach aspects of the Leaving Certificate in the Transition Year, with teachers not wanting their students to fall behind. Teachers are also wary of departing from familiar practices and express concern about having to teach 'outside the box', without the security of routine practices and a familiar syllabus to rely on. Previous research in schools (Hargreaves, 1989; Fullan & Hargreaves, 1992; Fullan, 1993; Hargreaves, Earl, & Ryan, 1996; Fullan, 2001; Hargreaves, 2003) tells us that change is difficult and leaving familiar and 'cosy' practices in order to change teaching traditions is not an easy task.

The Transition Year Programme provides an opportunity to develop scientific literacy outside the confines of a prescribed curriculum and without the constraint of an external examination.



This is of vital importance for participation in a global society (Krajcik & Sutherland, 2010), as traditional school science frequently fails to tackle current and relevant issues (Osborne, 2002; Childs, Hayes, Lynch, & Sheehan, 2010). Within the broad guidelines laid down for the Transition Year, the teacher is free to innovate and introduce students to a broader and more relevant view of Science. However, our research shows that the majority of teachers are not taking this opportunity to widen their students' view of Science but are instead teaching predominantly from the Leaving Certificate Science curricula (Childs et al., 2010; Hayes et al., 2010; Hayes, 2011).

The findings above reinforced earlier anecdotal findings that Science teachers struggled to find suitable material to teach in the Transition Year and were dissatisfied with the way Science was taught but were ill-equipped, in the main, to design their own courses and materials. There was clearly a need to produce suitable materials to help teachers use the Transition Year more effectively to bridge the gap between junior and senior cycles.

### TY Science project

The recurring issues in Transition Year Science appeared to be that teachers were struggling to produce and develop relevant and appropriate teaching materials for Science in the Year. The 'TY Science' Project was developed at the University of Limerick in order to address this issue. The project has been running at the University of Limerick since 2002-2003, with the aim of developing innovative 'TY Science' modules with an STS emphasis. The overall goal of the project is to develop scientific literacy, arouse students' interest in Science and encourage them to continue to study Science in the senior cycle. The project, which will be outlined over the subsequent pages, is a longitudinal study and followed Reeves' (2006) approach to Design Research and the framework of Participatory Action Research (Eilks & Ralle, 2002). Figure 3 illustrates Reeves' (2006) approach to design research.

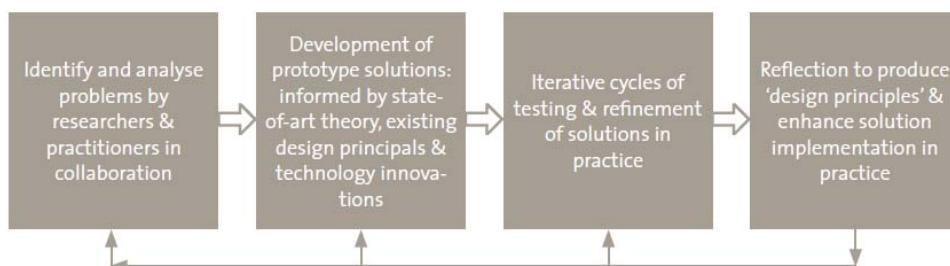


Figure 3: Approach to design research (Reeves, 2006)

As the Transition Year is a year without a formal curriculum or examination, it offers an opportunity for educational innovation. However, this is not being realised in practice. Van den Akker (1999, pp.8-9) describes design research as something which not only aims to provide an innovative solution to an educational problem rather than testing a theory, but also to create a 'practical and effective intervention to a real world problem'. Van den Akker (1999) also iterates the importance of interaction with practitioners. This led the design team to consider developing science teaching materials for this year. In addition, fourth year pre-service science teachers often teach Transition Year classes in the final teaching practice of their degree programme, but they also were not able to find suitable materials without producing them themselves. This led to the start of the TY Science project in 2003, when two students were encouraged to develop and teach contextualised modules on Cosmetic Science and Forensic Science during their final teaching practice. However, these first modules were not formally evaluated but were revised in

the light the students' own experience of teaching them. A later student then developed a module on the Science of Sport, and was also involved in revising the two earlier modules; this student did get other teachers to try the materials and the module was formally evaluated through student and teacher questionnaires, as described below. This was the real start of the TY Science project., whereby a fourth year pre-service science teacher would design, develop and teach a 'TY Science' module on teaching practice, and would also involve other pre-service science teachers and practising science teachers in trialling the materials. The effectiveness of the materials would be evaluated in a number of ways and the information used to correct, revise and modify the materials. They were then made available to teachers for a wider trial and teachers were encouraged to send back feed-back on their use. The overall design process that was developed is shown in Figure 4. Effectively, each 'TY Science' module which was designed developed and trialled became a small case study in curriculum development, which led to further reflection and refinement of the design criteria developed from the project, and eventually to the formulation of design principles.

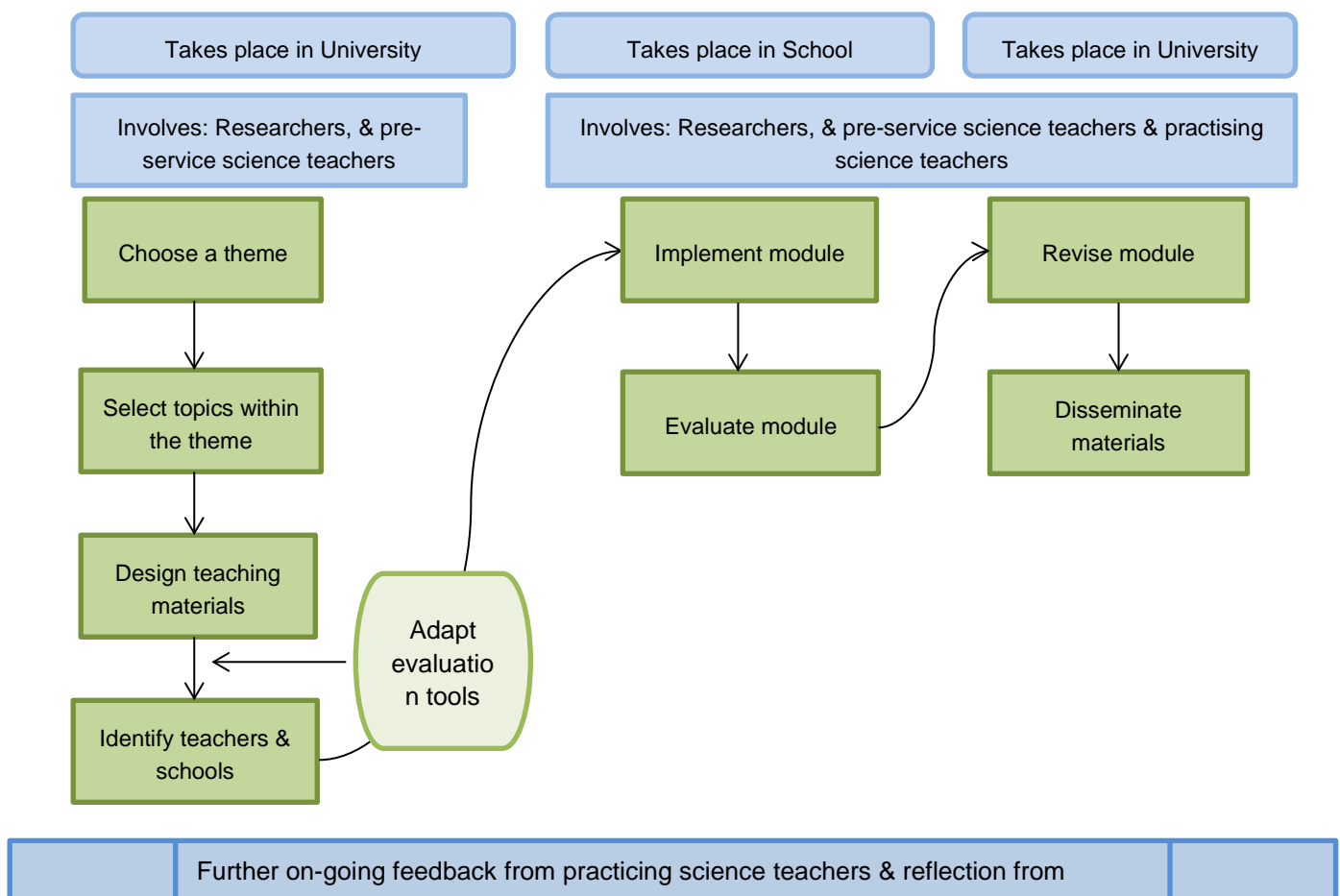


Figure 4: Outline of the curriculum development process used in the TY Science project

The pre-service science teachers developing 'TY Science' modules were given a number of criteria to follow, in order to align their modules with the main outcomes expected from modern science education and also to provide a suitable bridge between the junior and senior cycles. These criteria stemmed from an extensive literature review examining science in the Transition

Year and in science education in general. The following criteria were given to pre-service science teachers in their initial design brief, the TY Science module:

- Builds on the Junior Science Course;
- Relates Science to everyday life (STS);
- Develops communication skills;
- Develops ICT skills;
- Develops practical skills;
- Develops inquiry and investigative skills;
- Fosters group work;
- Develops scientific literacy, and
- Encourages an interdisciplinary perspective, bringing in all the main Sciences, depending on the topic.

A constructivist framework was adopted, focusing on allowing the pupils taking the module in TY science, to create their own knowledge and understanding in a science context and through practical activities with an emphasis on active learning and inquiry. Many pupils are turned off science because it seems irrelevant to their lives and they see it as confined to the school laboratory (Osborne, Simon, & Collins, 2003, p. 1049; Osborne & Dillon, 2008; Bennett & Hogarth, 2009). Thus the 'TY Science' project has also drawn on context-based curriculum projects in science (Smith & Matthews, 2000; Parchmann et al., 2006; Schwartz, 2006) and approaches from the Science Technology and Society (STS) movement, to contextualise the science and make it both relevant and attractive to pupils. There is also a move in modern education to develop skills as well as knowledge, including ICT and communication skills, often referred to as transferable skills (Osborne & Dillon, 2008). These are valuable in all subjects, not just science, but also in a real life. The 'TY Science' modules thus seek to develop communication and ICT skills within the context of the Science topic. These design criteria have themselves been developed and refined over the course of the on-going project, which has now seen the development of fourteen original TY science modules (Table 3). Eight of these have been disseminated so far and are widely used by teachers; the others are in various stages of revision prior to dissemination. Many copies of the 'TY Science' modules are now in use in Irish schools and there is a steady demand for them. What has not been done yet is a wider-scale evaluation over a longer timescale of the effectiveness of the modules, although this is planned.

Table 2: The titles, authors and dates of production of TY Science modules

Module title	Author	Year of publication/production
Forensic Science	Sindy Meleady	2004
Cosmetic Science	Audrey O'Grady	2004
The Science of Sport	Maria Sheehan	2004
Air, Earth, Fire and Water: Environmental Science	Sarah Hayes	2007
Science of Survival	Rebecca Moran	2007
Issues in Science	Ciara Hayes	2009
Food Science	Anne O'Dwyer	2009
Space Science and Technology	Walter Mahony	2009
Science and Medicine	Karen Murphy	2009
Waste not, Want not	Hannah Murphy	2011
Power to the People	Nicholas Ryan	2011
Smart Materials	Martin Sheehan	2012
The Science of Toys	Joannah Kennedy	2012
Analytical Chemistry	Eva Dunne	2013

The initial idea for the module is developed through consultation between the student and science educators, but during the course of the trial phase other pre-service science teachers (fourth year students) and practising and experienced science teachers are involved and their view are sought. This is described in more detail in the case study below.

## 5. Results of the project

Given the time span of this project the results will be presented in the form of a case study, looking at one of the 'TY Science' modules. This approach has been chosen as case studies allow "an investigation to retain the holistic and meaningful characteristics of real life events" (Yin, 1994, p. 3). One of the authors (O'Dwyer, 2009) developed a 'TY Science' module on Food Science for her Final Year Project in 2008-9. The specific topic of Food Science was chosen as one that would interest the students aged 15-16 and that would connect with their everyday lives. It was not chosen specifically with girls in mind, and has been taught in mixed classes. The specific themes for each unit (see Table 3) were chosen to illustrate different aspects of food science, and to supplement material covered the junior cycle science course done previously (as well as in the domestic science course) and the subsequent senior cycle Biology course. The design criteria described above in were used in the construction of the units. Each unit has a defined format: one single, one double (including practical work) and an optional single lesson. The module consists of eight units, each covering one week's work, and are supplied in the form of a photocopiable Student's Handbook and a Teacher's Guide. In constructing the lessons a grid was drawn up to indicate where the criteria were being met and which skills were being developed in the various units. This was to ensure that all the criteria were met and that the key skills were met with more than once during the course of the module.

Table 3: Units in the Food Science module

1. A taste for more	5. Food spoilage
2. The nutrients	6. Science of cooking
3. Food additives	7. Mmm ,,, Tasty!
4. Food processes	8. Milk it!

Table 4: A design grid showing the skills developed and criteria met in the units

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
Building on J.C. Science	√	√	√	√	√	√	√	√
Independent Learning	√				√	√	√	√
Pair / Group work	√	√	√	√		√	√	√
Development of I.T. skills		√	√		√			√
Development of Literacy skills		√	√	√	√	√		√
Development of Communication skills			√	√			√	√
Development of Laboratory & practical skills	√	√	√	√	√	√	√	√
Active-Learning Methodologies			√	√			√	√
Relevance to pupils' lives	√	√	√	√	√	√	√	√
Links to Biology	√	√	√	√	√	√	√	√
Links to Chemistry	√			√	√			√
Links to Physics	√		√			√		
Links with industry	√	√	√	√	√	√	√	√

The module was taught by the author (AOD) and five other practising science teachers were recruited, giving six schools in total. In the end the module was only taught and evaluations returned by the author and two other schools. This involved 3 classes and a total of 62 pupils, 82% of whom were girls. The evaluation involved a pre-module pupil questionnaire, a teacher's diary to be kept during the teaching of the module, and a post-module pupil questionnaire and a post-module teacher questionnaire. The combined use of the pupil questionnaires and the teacher questionnaire, as well as the teacher diary, provided a range of sources of information to evaluate the effectiveness of the module. The pupil questionnaires were designed to investigate:

- The pupils' general attitudes towards science.
- The pupils' general attitudes towards the relevance of Science Education to their own lives and the real world.
- The pupils' general attitudes towards the structure, content and effectiveness of the Food Science module.

- Whether the Food Science module influenced the pupils' interests or attitudes toward science in any way.

A series of three research questions (Q1, Q2 and Q3) were formulated at the start of the module development and the questionnaires were analysed using SPSS in order to answer these questions. A summary of the findings is given below for each question.

**Q1. Will the experience of a Transition Year Science module influence whether or not pupils decide to study a Science subject for the Leaving Certificate?**

From the analysis of the results from the three schools, an overall increase of 22% (14) was observed in the number of Transition Year pupils choosing a Science subject to study for the Leaving Certificate. This indicates that the experience of the Food Science module had some influence in determining the pupils' choice of subjects for the Leaving Certificate. It must be acknowledged however, that for the most part the module was not effective in determining which subject the pupils choose to study. It was not surprising that biology had the greatest uptake, since the Food Science module was most closely linked to biology and research has indicated that pupils are more predisposed to study biology compared to the physical sciences (Osborne *et al.*, 2003; Smyth and Hannon, 2006).

**Q2. Will the experience of Science taught in a creative, and practical manner aid the pupils' understanding of Science?**

Through their involvement in a creative and hands-on Food Science module, pupils reported enjoying their experience of science. Pupils enjoyed the practical work and investigations, learning about food, the nutrients and food groups. The pupils enjoyed working independently as well as part of a group taking responsibility for their own learning. 68% (42) of the overall 62 pupils agreed that it is easier to learn science when working in small groups. Through the use of everyday experiences, and by encouraging the pupils to apply their practical knowledge, the pupils developed a coherent understanding of science and its relation to food in particular. In total 87% (54) of the total 62 participating pupils agreed that the use of practical work facilitates their understanding of science.

**Q3. Will the experience of a Transition Year Science module influence pupils' attitudes and perspectives towards Science?**

In comparing the pupils' attitudes to science before and after their experience of the Food Science module, there was an increase of 19% (12) in the number of pupils recognising the importance of learning science in school. In total 90% (56) of the overall 62 pupils acknowledged the importance of learning science in school after their experience of this Transition Year module. A significant 85% (53) of the 62 pupils agreed that science has relevance to their own lives following the module. By understanding the importance of learning science in school and in their own lives, these pupils may be more motivated in their aspirations to continue their study of science. An increase of 8% (5) of the 62 participating pupils recognised the important role that science plays in Industry through their experience of this Food Science module. After their experience of the module 90% (56) of 62 participating pupils agreed that science plays an important role in Industry.

The small number of teachers involved (3) limited the value of their questionnaires, although the diaries were helpful in identifying flaws and problems in the written materials and activities. These views were used in the revision of the module before its wider dissemination. All of the participating teachers agreed that the Food Science module:

- Facilitates pupils, understanding of science.
- Gives an introduction to all of the sciences for Leaving Certificate.
- Improves pupils' attitudes towards science.
- Improves pupils' knowledge and skills in science.
- Is relevant to pupils' everyday lives.

The evaluation in this case study for this module is limited by the small number of schools and pupils involved; the fact that two of the teachers were final year students; and the failure to teach all the units in each school. However, this case study shows the value of pre-service science teacher-designed teaching materials in helping to introduce new ideas and teaching approaches into the teaching of science. The module was revised and corrected in 2009 at the end of the intervention and since that date has been widely used in Irish schools; it has not yet undergone further evaluation, which still remains to be done. Lessons learned in the design, implementation and evaluation of this module have been used by students designing subsequent modules for the 'TY Science' project, as there is continuing feedback into the project from the experiences of each student and their own module. A further small scale examination of what resources TY science teachers are using was carried out by Hayes (2011) as part of a wider study into the Transition Year. These findings indicated that a large proportion of TY science teachers (N = 73, n = 31 42.5%) were using the 'TY Science' modules as teaching resources in the Transition Year.

## 6. Reflection: Lessons learned

The experience gained during the ten years the project has been running has led to the refinement of the criteria but also the formulation of design principles, in line with Design Research (Plomp, 2009), and has also exposed the limitations and weaknesses of the project. The following design principles have resulted from the experience gained during the project.

1. It is important to identify science topics which are of interest to pupils, and which will be effective vehicles for teaching and learning science. Thus, forensic science is always popular following the success of various television programmes, and cosmetic science is popular in all-girls' schools. Working with pre-service science teacher, who are close in age to the school pupils, helps in choosing suitable topics.
2. The materials must be produced in a format that makes it easy for teachers to use them in schools (e.g. photocopiable student handbooks) and must use readily available and low-cost materials, in order to encourage teachers to use them.
3. The materials must consistently aim to develop scientific literacy through the use of real contexts and an STS focus, so that pupils are encouraged to relate school science to applications and issues in the real world.
4. Every unit, which covers one week's work, must include pupil activities and inquiry-based tasks, in order to motivate pupils but also to develop scientific process skills and a habit of inquiry, and allow them to construct meaning for themselves.
5. To place the applications and examples in a relevant scientific context, it is important that the material in the units and the teachers link the material to what pupils have done before, building on previous knowledge, and also introduce and develop any new scientific ideas at the start of the unit.
6. The material must be presented in a way that allows teachers, who are often coming to the materials cold without formal preparation, to be able to utilise them easily in the laboratory.

7. Motivating pupils is one of the key issues in teaching school science and this is particularly important in the Transition Year, which is outside the formal curriculum. It is this important that the mix of activities and the context in which the science is developed is both interesting and challenging, in order to arouse and sustain pupil motivation.
8. The TY Science modules have highlighted the importance of transferable or soft skills in teaching science, both for use within Science and outside, and so there is a strong emphasis on ICT, communication skills and creativity in the modules.
9. The teachers must be clear on the philosophy, approach and teaching methods being used in the TY Science modules if they are to be implemented properly, and so the teachers are provided with a teacher's guide which gives them the necessary background information. TY Science aims to change the teaching experience for the teacher as well as the learning experience for the pupil.

There have also been, and continue to be, on-going limitations of the project. The TY Science project has a number of limitations, which hinder its effectiveness as a Design Research project. These are mainly due to the short time-frame under which each phase of the project is conducted; the nature of the Transition Year experience itself; the inexperience of the student teachers who develop the modules; the lack of preparedness of the practising teachers to adopt new teaching approaches and their unfamiliarity with the module topics; the limited opportunity for evaluation of each module on its first outing; the lack so far of a longer-term and larger-scale evaluation of the materials after several year's use. Each of these limitations will be considered briefly below.

1. The project has developed to involve final year pre-service science teachers and so must work within the time constraints of their final year project (September to April) and of their teaching practice (9 weeks). This limits the time for producing, teaching and evaluating the modules.
2. There is difficulty in recruiting enough pre-service science teachers and practising teachers to trial the modules within the timescale of the implementation.
3. There is a problem in getting all those who agree to trial the module both to complete it, i.e. to teach all eight units, and/or to send back the evaluations and feedback, thus leading to a small sample size for evaluation.
4. There has been a failure to-date to do a larger scale evaluation of the materials in use in schools, over a longer timescale and with a greater number and range of schools, and including the whole set of modules. This evaluation is overdue, as there are now hundreds of copies of the modules in use in many schools and over several years.
5. The inexperience of the pre-service science teacher authors in both subject matter knowledge and in teaching experience limits the quality of the materials and also affects their implementation and evaluation by the pre-service science teacher authors. However, it offers pre-service science teachers an invaluable experience of curriculum design, and implementing research into their own classroom practice.

The overall popularity of these modules in Ireland, despite the availability of other educational materials for Transition Year teachers and pupils, has led the authors to reflect on what has made these modules a success. We believe a number of factors are involved, based on our own assessment, the surveys done by Hayes (2011) and informal feedback from teachers:

- The collaborative involvement of science educators, pre- and in-service Science teachers in the process of development,
- The context-based, active learning approach to science adopted,



- The low-cost nature of the materials, and other resources which may be necessary for implementation of the modules,
- The wide range of inter-disciplinary topics available, covering relevant and popular themes.

## 7. Conclusions

The Irish Transition Year (TY) between the junior and senior second level cycles offers a unique opportunity to change the way Science is taught, without the constraints of a formal curriculum and terminal examination. However, our research shows that most teachers are not equipped to take advantage of this opportunity to innovate and default to teaching material in a traditional manner from the senior cycle Science curriculum. This is mainly due to a lack of preparedness among teachers for developing their own courses and points to deficiencies in both pre-service and in-service provision. The innovative curriculum project at the University of Limerick, TY Science, has attempted to fill a gap in the provision of suitable teaching materials for the Transition Year and to change the way Science is taught. A major feature of TY Science is the involvement of trainee Science teachers in the development of novel, STS-based, inquiry-based, interdisciplinary Science modules, working in partnership with experienced teachers and Science education specialists. This has proved to be a very successful approach and the project has provided Irish Science teachers with a wide range of materials to use in the Transition Year. The materials are widely used and small-scale evaluation has indicated their effectiveness in improving students' attitudes towards Science and increasing uptake into subsequent Science courses. The TY Science materials developed in this project are helping Irish Science teachers to make better use of the opportunity afforded by the Transition Year, and are also helping in a small way to change the way Science is taught in Irish schools.

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## Design Research on Developing Teaching Repertoires

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Credits



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# 36. Design research on developing teaching repertoires

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## Abstract

*In the last decades, roughly two complementary approaches have been developed for supporting teachers in developing their teaching repertoire: models of reflection, and general instructional design models. These approaches can complement each other; however, the support they provide for teachers still remains limited. In this chapter we report on the design and results of a 10-year design research project that aimed at integrating the two approaches and compensating for their limitations. We describe how, in five main research phases, we developed a new method to support secondary school teachers in extending their teaching repertoire with effective innovative teaching approaches. This method was underpinned by theoretical insights, but aimed to support teachers in a very practical way: instrumentally, congruently, and at a low cost. The practical aspects are essential, as any form of teacher support can only succeed in practice if teachers evaluate it as practical. We show how each successive research phase led to further development of our method and its theoretical underpinning, as well as raising new specific research questions.*

## 1. Introduction

It is important for teachers to continue developing and expanding their repertoire throughout their teaching careers (Janssen, De Hullu, & Tigelaar, 2008). 'Teaching repertoire' refers to the different means a teacher has at his disposal for teaching subject matter. A teacher who has a broad teaching repertoire is able to approach topics from different angles and can draw on different instructional strategies for doing this, for example by means of direct instruction or guided discovery learning. In secondary education, however, teachers generally develop a limited repertoire. Teaching experience typically leads to a more efficient use of such a repertoire, but not to substantial innovation within the repertoire (Darling-Hammond, & Bransford, 2005; Borko & Putnam, 1996). A wide-ranging teaching repertoire enables teachers to respond flexibly to students' varying capacities and interests, to changing teaching contexts, and to pedagogical innovations. Furthermore, teachers who are able to continuously expand their teaching repertoire are more likely to experience teaching as a challenging and fulfilling activity, as this enables them to put their ideals into practice.

The present study was conducted primarily in the context of biology teacher education. The study initially had a twofold aim. The primary aim was to develop a method that supports biology student teachers in expanding their repertoire. The secondary aim was to contribute to the development of theory concerning *how* biology student teachers develop their repertoire and how this can be supported. These theoretical reflections were intended to underpin our method and explain the effects observed. As we explain below, in the course of the study its scope broadened to include other subjects and experienced teachers.

The present study started with the formulation of three criteria for a professionalization method of this kind: it must lead to effective instruction strategies that promote student learning (*effective*). However, there are several ways to realize effective teaching (Reigeluth & Carr-Chellman, 2009). Therefore, the professionalization method must enable teachers to continually

explore new ways to design instruction, in such a way that they continuously expand their repertoire (*generative*). Finally, the method must be practical for teachers (*practical*). Any form of teacher support can only succeed in practice if teachers evaluate it as practical. Doyle and Ponder (1977) not only pointed to the importance of practicality, but also specified criteria that teacher support must meet if it is to be considered practical by teachers. For teachers, support is practical if it:

- a. provides teachers with efficient procedures that enable them to realise new repertoire (instrumentality);
- b. aligns with and builds on the teacher's current teaching repertoire (congruence);
- c. does not cost too much in terms of extra time, information, or tools, and therefore pays off within a limited time span (cost-benefit trade-off).

This led to the following central question underlying the research:

*What are characteristics of a practical method that supports teachers in extending their effective teaching repertoire, and how can this method be theoretically underpinned?*

Our research project aimed at a twofold yield: a tested intervention, and theory development. Design research is ideally suited to this purpose (Plomp & Nieveen, 2009). In design research, both an intervention and the underlying theory are developed simultaneously, in a spiral process of theoretical reflection, design, and testing. In this chapter, we first we present the initial theoretical framework and method for the study. Next, we present the overall research design: the study as a whole can be seen as a sequence of design research studies ('phases'). In subsequent sections, we outline the various individual research phases and show how the results of each phase led to refinement of the method, theoretical framework, and research questions, and in some cases the scope of the overall study. Some of the component studies that make up this research project have already been presented in detail in earlier publications. These publications will be referred to in the text below where relevant. We conclude by summarizing some of the lessons learned about how design research can contribute to theory development.

## **2. Initial theoretical framework**

Roughly two complementary approaches have been developed for supporting teachers in developing their teaching repertoire: models of reflection (Lee, 2005), and general instructional design models (Gustafson & Branch, 2002). Below, we discuss how these approaches complement each other, and where their limitations lie. We aim to integrate the two approaches and compensate for the limitations discerned.

Dewey (1910) emphasized the importance of *reflective learning from experience* in the step-by-step development of a teacher's teaching repertoire. Since Dewey, many approaches have been developed that support teachers' reflection (see Lee (2005) for an overview). De Groot (1969) shed light on the essence of reflective learning from experience by comparing it to learning from experience *without* reflection. In the latter case, a teacher simply responds to a situation and if the effect suits him, he will show the same response if a similar situation occurs. If the effect does not suit him, he will either avoid the situation in the future, or change his response. Reflective learning from experience differs from this in that the teacher becomes more aware of the characteristics of the situation he responds to (1), and will be better able to decide which characteristics are essential (2). He is also better able to explicate the goals he wants to realise within that particular situation (3), and to consider possible reactions in view of those goals (4). After the responses (5), he can establish more accurately to what extent his actions have led to realising his initial goals, and what he can learn from this for responding to

future situations (6). Finally, on a meta-cognitive level, a teacher becomes increasingly aware that reflective learning from experience requires him to explicitly go through all six phases. Most of the reflective learning approaches place the different phases of reflective learning as described by De Groot (1969) in a cyclic process, and sometimes add questions meant to invite teachers to reflect on a specific part of the process (Lee, 2005). These models have proven to be valuable. However, the depth of the reflection has proven to depend to a significant extent on the teacher's practical knowledge: i.e., the combined knowledge and insights that underlie teachers' actions in practice (Verloop et al., 2001). Teachers need a conceptual framework to design and analyze lessons (Darling-Hammond & Bransford, 2005; Janssen et al, 2008). These findings are consistent with insights from the philosophy of science, which show that existing ideas function as a searchlight: they determine what you see, and how you interpret what you see. If your 'searchlight' is limited, then what you learn from experiences will also be limited (Popper, 1972).

Since the 1950s, many instructional design models have been developed that provide teachers with that searchlight, in the form of a conceptual framework for designing and analysing their lessons (see Gustafson & Branch, 2002 for an overview). These models specify what a teacher needs to consider when designing or analysing lessons: objectives, starting situation, content, representations, teaching-learning process, and assessment. Research shows, however, that although almost every teacher is educated in the use of these models, neither novice nor experienced teachers tend to use them much in actual practice (Yinger & Hendricks-Lee, 1995). The limited impact of these instructional design models can be explained in light of the criteria, discussed above, that any method must meet in order to support the expanding of teaching repertoire: that it should be effective, generative, and practical. First of all, applying instructional models of this kind does not necessarily lead to effective instruction. Second, such models are not generative, since they do not offer support for developing new ways of instruction. Finally, the models are not practical, in that they do not provide time-saving and information-saving procedures that teachers can use to develop new repertoire, building on their current repertoire (Janssen, Van Driel, & Verloop 2010).

We can conclude then, that the two traditional approaches for the development of an effective teaching repertoire can complement and reinforce one another, but that their effectiveness proves limited. In principle, a reflective approach could support teachers in learning from experience and could contribute to gradual expansion of their teaching repertoire. What is essential in this process is that teachers possess a 'searchlight' to enable them to identify the essential components of their lessons. Instructional design models can, to a certain extent, fulfil the function of a searchlight, by providing guidelines for what teachers need to think about when designing and analysing lessons.

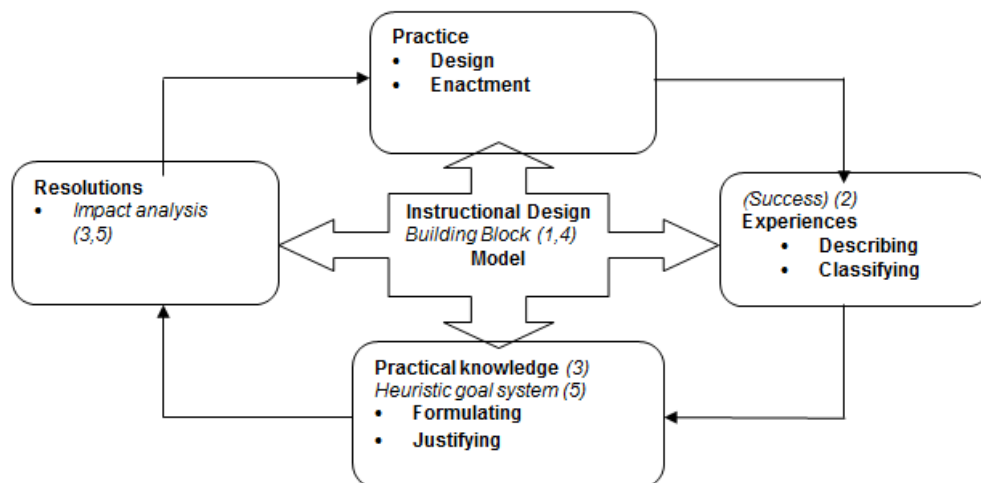


Figure 1: Components of the method we developed to support teachers in expanding their teaching repertoire.

The components of the integrated method that formed the starting point of the design research are shown in bold. The aspects that were added successively in the various research phases are shown in italics. The numbers indicate the research phase in which a given aspect was added.

The present design research therefore integrates the two approaches (Figure 1). The aim of this design research is to further develop this integrated method in such a way that it meets the three criteria for teacher support: that it will be effective for student learning, as well as generative and practical for teachers.

### 3. Method

#### Context and participants

The present method combines theory and practice. Over the course of the past ten years, it has been developed and tested within two main contexts: at the teacher training institute of Leiden University (ICLON) and within school-based professional development programs in the Netherlands. Both of these contexts involve secondary-school teachers. Several cohorts of student teachers, in-service teachers, and teacher educators for various school subjects have participated.

The student teachers generally have a master's degree in the discipline they are going to teach at school. They then take a one-year teacher training course, that leads to a qualification to teach at all levels of secondary education. Student teachers take courses at university for one day a week; on the remaining days they teach about 10 hours a week at a school, under the supervision of an experienced teacher. At university, the student teachers follow a one-year program, consisting of courses both on generic topics, such as teaching strategies and classroom management, and on subject-specific teaching methods.

The greater part of the present design research at the ICLON was carried out with biology student teachers, as part of their subject-specific methods course. However, many student teachers of other school subjects were also involved (Table 1), as well as their teacher educators. These teacher educators were involved as experts in various stages of the design research, to develop and validate the method.

Table 1: Participants in the design research

Participants Number	
Student teachers	
• Biology	245
• Other subjects	110
Experienced teachers*	
• Science	145
• Other subjects	231
Teachers of subject-specific methods course	
• Biology	7**
• Other subjects	14

\*) Teachers with at least 5 years' teaching experience.

\*\*\*) Two from ICLON and five teacher educators from other teacher education institutes.

Additionally, aspects and variants of the method were applied and tested in several professional development programmes for experienced teachers of various subjects. These professional development programmes were school-based and offered by the ICLON. In the first five years, the programmes involved were mainly those for science and mathematics teachers; afterwards the scopes of the programmes were broadened to all the subjects (Table 1).

### Research phases

In design research, an intervention and the underlying theory are developed simultaneously in a spiral process of theoretical reflection, design, and testing. In the present research, that covered 10 years, five successive phases can be distinguished, each of which lasted 2-3 years. Each successive main phase led to additions to the method and its theoretical underpinning, and thus also to new research questions. Table 2 presents an overview of the main phases, questions, and key instruments for data collection, in order to assess the impact of the evolving method for expanding a teacher's repertoire, in the light of the criteria discussed above: i.e. the extent to which the method is effective for student learning, and practical and generative for teachers. Table 3 shows how the method and its theoretical underpinning evolved in the course of the design research.

In each main research phase, several steps can be distinguished (see Table 2). First, the formulation of the central research question of that phase is followed by a literature review, in order to establish which theories might prove useful for finding practical solutions for the newly raised questions. On the basis of such new theoretical insights, a prototype of the teacher support method is developed, presented to experts, and refined. Next the prototype is piloted within the target group. The final version of the prototype is generally enacted among both the biology student teachers and experienced teachers and evaluated by means of a series of quasi-experimental studies. These individual studies have been published. The final step of the research phase is the results section, in which the results of the research phase in question are discussed and references are given to the relevant publications. Table 4 provides an illustration of the steps in Phase 2.

Table 2: Overview of the overall design research and its successive questions and corresponding research phases, the steps within each research phase, and the key instruments for data collection

<b>Design Research on How to Expand Teaching Repertoires</b>	<b>Phase 1 2003-2005</b>	<b>Phase 2 2005-2008</b>	<b>Phase 3 2008-2009</b>	<b>Phase 4 2009-2011</b>	<b>Phase 5 2011- current</b>
<b>Research question</b>	How can we elaborate the instructional design model so that teachers learn to explore new possibilities for lessons in a practical way?	How can we stimulate teachers to implement innovative lesson designs in class?	What do teachers learn from experiences, and how does their practical knowledge direct their design and enactment?	What building blocks could be developed for a general building-block model with a domain-specific complement?	How can a teacher's practical reasoning when designing a lesson be elicited precisely, in order to establish a practical manner to expand teaching repertoire?
<b>Steps within each research phase</b>	Literature study Developing a prototype of the intervention, and walk-through with experts Pilot of the revised prototype within target group Experimental or quasi-experimental studies and/or multiple case studies to test the intervention				
<b>Participants involved in the various steps of the research phase</b>					
<b>Student teachers</b>	55	65	65	78	87
<b>Experienced teachers</b>	23	43	49	156	150
<b>Teacher educators</b>	7	10	19	21	19
<b>Key instruments for establishing impact of method in developing a teaching repertoire Effective for students</b>	Lesson plan analysis with criteria for effective teaching (CET) checklist	Analysis of teachers' resolutions using CET checklist Student tests	Analysis of lessons with CET checklist.	Analysis of lessons using CET checklist. Scoring of CET by the students. Student tests	Analysis of lessons using CET checklist. Scoring of CET by the students. Student tests
<b>Practical for teachers</b>	Scoring overall practicality of innovative lesson design strategy on 7-point Likert scale, with explanation	Scoring strength of intentions and listing of motivational beliefs	Scoring strength of intentions and listing motivational beliefs. Thinking through design protocols of teachers aloud	Scoring of practicality criteria, with explanation.	Teaching impact analysis. Scoring strength of intentions and listing motivational beliefs
<b>Generative for teachers</b>	Analysis of multiple lesson formats that teachers designed about the same topic using instructional design model	Scoring motivation and innovativeness of design decisions	Analysis of rules of thumb developed by teachers	Analysis using model of lessons, intentions, and self-assessment on development of innovative lessons over period of 3-9 months	Analysis, using the building-block model, of lessons and changes in heuristic goal system and self-assessment on development over a period of 3-9 months.

Table 3: Evolving research questions, method and theoretical underpinning

Phase	Motive and central question	New aspects of the method (see figure 1)	New aspects of the theoretical basis
1	<p>General instructional design models are not effective, nor practical and generative for teachers.</p> <p><i>How can we elaborate the instructional design model so that teachers learn to explore new possibilities for effective lessons in a practical way?</i></p>	<p>The components of the instructional design models are elaborated with <i>domain-specific building blocks</i>. The building blocks can be selected and combined to design a great diversity of biology lessons (1 in Figure 1).</p>	<p>Innovation by recombination of existing building blocks (Holland, 2000)</p>
2	<p>The domain-specific building blocks enable teachers to design a variety of different lessons, but teachers do not implement their innovative designs in their classes.</p> <p>How can we stimulate teachers to implement innovative lesson designs in class?</p>	<p>Teachers are stimulated to learn if they experience success using a new instructional strategy, or aspects of it. They can then build on these positive experiences step by step (instead of learning from mistakes, as is usually the case in reflective learning approaches) (2 in Figure 1)</p>	<p>Insight into necessary required and sufficient conditions for acting (Smedslund, 1997)</p>
3	<p>Learning from success leads to the teachers expanding their repertoire step by step, and to teachers being more motivated to implement their design. It is unclear, however, what exactly teachers learn from their experiences (of success or otherwise).</p> <p><i>What do teachers learn from experience, and how does their practical knowledge direct their design and enactment of lessons?</i></p>	<p>On the basis of their experiences, teachers formulate 'rules of thumb' that direct their thinking and acting. We therefore stimulate teachers to formulate what they have learned in terms of rules of thumb. (3 in Figure 1).</p>	<p>Behaviour guiding aspects of practical knowledge: rules of thumb (DeGroot &amp; Medendorp, 1986)</p>
4	<p>The domain-specific building block model for biology works, but has a limited scope of application. We want to know if it is possible to develop a more general building-block model that can be applied for each subject in a domain-specific way.</p> <p><i>What building blocks could be developed for a general building-block model with a domain-specific complement?</i></p>	<p>General building blocks are formulated for the following components of the instructional design model: goals, instructional strategies, and teaching-learning process (4 in Figure 1)</p>	<p>Theory on building blocks and criteria for a teaching repertoire (Janssen, 2012).</p>
5	<p>A teacher's practical reasoning is guided by rules of thumb, but it is still unclear how these are related to each other and to a teacher's goals, and therefore how they direct behaviour.</p> <p><i>How can a teacher's practical reasoning when designing a lesson be elicited precisely, in order to establish a practical manner to expand teaching repertoire?</i></p>	<p>The practical reasoning of a teacher and his behaviour is guided by a hierarchy of goals and connected heuristics to realise those goals (heuristic goal system (HGS). A teacher's HGS can be elicited by means of the laddering procedure. On this basis, we can establish precisely how a new teaching strategy can be made practical for a teacher (impact analyse) (5 in figure 1).</p>	<p>Heuristic goal system theory is based on three recent theories on bounded rationality that describe how people think, act, and develop new action plans in complex practical situations (Janssen, Westbroek, &amp; Van Driel, 2013)</p>

## Steps within a main research phase, illustrated for Phase 2

### ***Literature study to identify relevant theories for building a prototype***

The central question of Phase 2 is: *How can teacher implementation of innovative lesson designs in class be achieved? How can we ensure that teachers actually implement their innovative lesson designs in class?*

To answer this question, we turned to theories on conditions for and the influencing of behaviour. Smedlund's theory on this was both the most simple and the most complete. Smedslund (1997) argues that a person will only carry out an action if he is *able* and *willing to try*. A person is able only if he has the appropriate relevant knowledge and skills. A person is willing if he expects that executing the action has more advantages and less disadvantages than the alternative *and* if he thinks he can execute the action successfully. Smedlund's theory helps explain why the biology student teachers did not implement the majority of the lesson plans they designed: not only must a student teacher feel that he is able to carry out a newly designed lesson, he also must judge that the advantages of this new lesson, in comparison to his regular lesson, outweigh the disadvantages. As the newly designed lesson concerns the enactment of new actions, the student biology teachers are likely to be insecure about possible effects, and whether they will be able to realize these new actions in class. Hence, to enhance the chances of the teacher being able and willing to enact a new lesson design, the support method should, on the one hand, build on the teacher's knowledge and skills. On the other hand, the new lesson design should take the regular teaching strategy a step further. Therefore teachers were stimulated to explore and build on earlier success experiences in class, incorporating aspects of their new lesson designs. A success experience relates to an innovative lesson or element of a lesson that the teacher has already put into practice in class, and which has led to positive experiences. By definition, a success experience of this kind is an action that the teacher is willing and able to carry out. By identifying earlier success experiences, and by exploring them and building on them, teachers can learn from these experiences and apply what they learned in the design of new lessons. They can now be expected to be generally more willing and able to enact (see Table 5 for an example, which includes aspects of Phases 3 and 4).

### ***Developing a prototype of the intervention, and walk through with experts***

A prototype of the intervention was developed on the basis of the literature review. Phase 2 consisted of a further elaboration of components from the method's reflection cycle (Figure 1). The aim was to productively elicit and build on success experiences. The procedure of the prototype (see below) was discussed with experts, i.e. teacher educators, and was then further refined. This led to the following procedure:

#### *Experiences (describing and classifying)*

- Describe a success experience: a lesson or part of a lesson you felt satisfied about.
- What made it a success for you?
- Use the domain-specific building block to analyse your success experience: which building blocks reflect the lesson learned from your success experience?

#### *Practical knowledge*

- What can you learn from this success experience for the design and enactment of other lessons?



### *Resolutions*

- Choose a lesson you could use to apply what you learned
- Consider whether there is anything still hindering you from applying what you learned for the design of this lesson, and think about how you could overcome his hindrance.

### *Design and enact practice*

- Use the domain-specific building blocks to design the lesson and teach it.

### ***Pilot of the revised prototype using target group***

The procedure was piloted using student biology teachers (n=21). They worked through the procedure, guided by a teacher educator who noted their responses to every question. The student teachers were also interviewed. On the basis of the results, the procedure was extended to include a variant on 'using successful experiences to learn from problems'.

### ***Quasi-experimental studies and/or multiple case studies to test the intervention***

Three quasi-experimental studies were conducted to test certain aspects of this intervention. In one study involving biology student teachers (n=16), the effectiveness of reflection on success experiences was compared with the effectiveness of reflection on problem experiences without using the building block model (Janssen et al, 2008). This study showed that learning from success experiences led to more innovative resolutions than did reflection on problems. Furthermore, as a rule, students turned out to be more motivated to try out resolutions based on learning from positive experiences, as compared to those resolutions based on learning from problems. In a follow-up study, also involving biology student teachers (n = 11), we compared reflecting on success experiences with and without use of the domain-specific model (Janssen, De Hullu, & Tigelaar, 2009). The results showed that use of the domain-specific model promoted better quality reflections. When using the model, student teachers' descriptions and explanations of their experiences were more detailed, they reflected on a deeper level, and their resolutions were more productive. In a third study, experienced biology teachers (n=8) participated in a PD program, based on the learning from success procedure and the building-block model, to learn to design and enact context-based biology lessons (Dam, Janssen, & Van Driel, 2013). In the PD program, teachers worked relatively independently within their own working environment. They built upon 'evident successes' and used the building blocks to change their classroom practice step by step towards context-based biology. Results showed that the teachers were willing and able to expand their repertoire step by step in this way.

### **Research instruments**

In this section we briefly discuss the various research instruments that were used to measure effectiveness, practicality, and the extent to which the method proved to be generative (see also Table, 2).

*Effective for students.* The effectiveness of the lessons in terms of learning processes and outcomes was measured as follows:

- Directly: written tests were used to measure to what extent the students attained the attainment targets.
- Indirectly: A checklist of criteria for effective instruction (e.g. achieves its purpose, allows sufficient time for learning) was developed on the basis of effectiveness studies (Hattie, 2009; Merrill, 1999). This checklist was used by the researchers to analyze lesson designs and as an observation scheme for analyzing the enactment of lessons. The enactment of

the lessons was sometimes additionally scored by the students. For this, a student version of the checklist was developed on the basis of the research checklist.

*Practical for teachers.* In various studies, at least one of the methods below was used to establish practicality.

- Teachers scored overall practicality on a 7-point Likert scale.
- Teachers scored criteria for practicality, instrumentality, congruence and low costs separately on a 7-point Likert scale. After this they were asked to explain their answers.
- Participating teachers scored their intentions to use a new teaching method on a 7-point Likert scale. They were also asked to explicate their motivational beliefs in a questionnaire based on Fishbein and Ajzen's model (2010) for explaining and influencing behaviour. They were asked about the pros and cons of the teaching method (attitude), whether important persons might approve/disapprove of the method (social norms), and perceived difficulties (control).

*Generative for teachers.* Finally, it is important to establish that the method supports teachers in continuously enriching their teaching repertoire. Therefore, the teachers need to be monitored for several years. As the support method was adapted frequently in the course of the long-term research, a longitudinal study of such permanent effects has not yet been carried out. However, various aspects were studied that are indicative for the generative character of the method.

- For a certain period after participating in the research (between three months and a year), participating teachers were asked to document their intentions with respect to expanding their teaching repertoire, and to score the strength of these intentions. At the same time, developments in their teaching repertoire were studied on the basis of lesson designs and enactment of lessons. Analysis was based on the instructional design model, which is explained in the next section.

## 4. Results

The aim of this design research project was to develop a method for extending teachers' teaching repertoire by integrating a reflective approach and an instructional design model approach (see initial theoretical framework). In each of the five research phases, the method was further developed, through the inclusion of elements that had turned out to be crucial. This process went hand in hand with the development of the theoretical underpinning of the method (see Table 2 and Figure 1). This ultimately led to a practical method for developing an effective teaching repertoire (*Model-based Learning from Success*), a theory on decision-making by teachers (*Heuristic Goal System Theory*), and a theory about teaching repertoire (*Teaching-repertoire Theory*). The results of each phase are briefly discussed below, with the exception of Phase 2, which was outlined before.

### Phase 1: Towards a domain-specific building-block model

The overall aim of this research was to combine reflective approaches to professional development and the use of instructional design models into one practical, integrated method. One problem is that existing instructional design models do not support teachers in a practical way as they seek to generate new lesson designs. The research question of Phase 1 was:

*How can we elaborate the instructional design model so that teachers learn to explore new possibilities for effective lessons in a practical way?*

We drew inspiration from the fundamental work of Holland (2000) on characteristics of both manmade and natural innovations. Holland shows that many innovations are in fact ‘recombinations’ of existing building blocks. With a limited number of building blocks and rules for recombination of blocks, one can create a variety of innovations in a practical (cost-effective, instrumental) way (cf. forming words using letters).

In the context of teaching, we aimed at to develop a relatively small set of building blocks and rules that would enable teachers to generate a vast diversity of teaching approaches by selecting and combining the building blocks. We formulated building blocks for content, teaching learning processes, and representation forms (see Janssen et al. (2009) for this version of the building block model). Due to limitations of space, we will here only present the building blocks for content, because building blocks for other components of teaching were revised substantially during the design research project (see Phase 4). Following Schwab (1964), we derived the building blocks for content from the 12 main ways of thinking in the life sciences (Janssen & De Hullu, 2008). Each perspective is elaborated with the inclusion of a key question and a strategy that can be used to answer such a question (Table 4). By selecting and recombining these building blocks for content, a vast variety of biology lessons can be designed. In Table 5, this is exemplified for lessons about the layers of the human skin.

*Table 4: Building blocks for content: Twelve perspectives in biology and accompanying questions*

<b>Perspective</b>	<b>Question</b>
Comparison	What are the similarities and differences with other biological or non-biological systems?
Cause	What is its cause?
Function	What is it for?
Mechanism	How does it work?
Environment	What does it need from its environment?
Development	How is it developed?
Evolution	How has it evolved?
Care	How can you take care of it?
Medical	How can you treat it if it goes wrong?
Technological	What can you do with it?
Ethical	What may you do with it?
Personal	How do you feel about it?

*Table 5: Three different lessons about the layers of the skin that were designed by selecting and recombining content building blocks in a different way (read left to right)*

<b>Lesson 1</b>		<i>Mechanism</i>	<i>Technology</i>
<b>Tattoo</b>		Teacher explains how the three layers of the skin work.	Teacher asks student how deep you have to stick a tattoo needle in order to make sure that the tattoo stays visible forever. Students try to solve this problem.
<b>Lesson 2</b>	<i>Technology</i>	<i>Mechanism</i>	<i>Technology</i>
<b>Tattoo</b>	Teacher asks the needle question (see right column above).	Teacher explains about the three layers of the skin.	Students solve needle problem.

*Table 5: Three different lessons about the layers of the skin that were designed by selecting and recombining content building blocks in a different way (read left to right) (continued)*

<b>Lesson 3</b>	<i>Comparison / Function</i>	<i>Function</i>	<i>Mechanism</i>
<b>Redesign the Skin</b>	Teacher asks students what the disadvantages would be if we had a plastic bag instead of a skin.	Students think of disadvantages (e.g. you can't sweat).	Students think of a solution for this disadvantage together with the teacher (e.g.: make holes in the bag) and the teacher explains how our skin solves this problem.

In addition to building blocks for content, teaching-learning processes, and representation forms, we have identified criteria to be met by every combination of building blocks in order to be effective, on the basis of the literature on criteria for effective teaching (see control component in Figure 2; Merrill, 1999).

Results of empirical studies testing these building block models show that, using the building block model, biology student teachers were able to design a larger variety of effective lessons, in less time, than students who had only a general instructional design model at their disposal (Janssen & De Hullu, 2007). Furthermore, the biology student teachers that used the building-block model were better able to formulate new lesson design intentions, because they had a better overview of the possible choices than did students who did not use this model.

Interestingly, although the student teachers showed that they were able to design a large variety of lessons, they only chose to enact a limited range of these lessons. This led to the question that guided the second phase of this research: How can we stimulate teachers to implement innovative lesson designs in class?

### **Phase 2: Towards the implementation of innovative lessons: learning from experiences of success**

Phase 2 resulted in a further specification of the reflection cycle as 'learning from success experiences'. Learning from success supports teachers in expanding their repertoire in a step-by-step manner: they are increasingly able to design more innovative lessons, and are increasingly motivated to enact their designs. It remained unclear, however, what exactly student teachers learned from their success experiences. This led to a new research question for Phase 3:

*What do teachers learn from experience, and how does their practical knowledge direct their design and enactment of lessons?*

### **Phase 3: Rules of thumb as representations of practical knowledge that guides behaviour**

Practical knowledge is often defined as what teachers learn from experience and theories and that guides their behaviour (Fenstermacher, 1994; Verloop et al, 2001). It is unclear, however, how one could represent behaviour-guiding aspects of knowledge. De Groot and Medendorp (1986) argue that behaviour-directing aspects of practical knowledge can be represented by rules of thumb. These are rules of action that prescribe - or less directly, suggest - what one should do in a specific situation to attain a certain goal. Rules of thumb have an 'if-then structure': if, in situation A, you want to achieve goal Y, then do X. Teachers that participated in this stage of the research were asked to formulate what they learned from a given experience (whether of success or of a problem) as rules of thumb. They were additionally asked to underpin these rules. For example: with respect to the goal component, they were asked: why do you consider this important? And with respect to the action component they were asked: how does this action lead to this goal? (Janssen, et al, 2008, see Table 6 for an example).

A descriptive study by Wieringa and colleagues shows that experienced teachers who think out loud as they are designing a lesson make spontaneous decisions that are based on formerly developed rules of thumb (Wieringa, Janssen, & Van Driel, 2011). The rules of thumb used by the teachers in this study appeared to be strongly related to intended lesson outcomes and broader teaching goals. The observations regarding teachers formulating practical knowledge in the form of rules of thumb resulted in the need to gain more insight in how a teacher's rules of thumb relate to one another and to the teacher's broader goals. This question was answered in Phase 5 of the design research project. At the same time, another question emerged, which was addressed in Phase 4. We had developed a domain-specific building block model that was only applicable in the domain of biology. The question arose as to whether it would be possible to develop a more general building-block model, while preserving the option of domain-specific elaboration. This resulted in the question: *What building blocks could be developed for a general building-block model with a domain-specific complement?*

*Table 6: Formulating rules of thumb by reflecting on a problematic experience using relevant success experiences*

<b>Problematic Experience</b>	In a class discussion about kidneys with grade 11 students, I could not succeed in engaging my students in answering the questions I posed. Some of them stared passively at the blackboard; others were busy with other things. At one point I just gave up and made them do tasks from the book.
<b>Desired situation</b>	Students are motivated to answer questions and search for answers with me.
<b>Relevant success experience(s)</b>	In grade 7 many students were motivated to ask questions and search for answers. In this class I brought in snails. The students, in pairs, were asked to think of questions they would like to ask the snail and write these down. After this, I collected all the questions and tried to answer them in a classroom discussion, together with the students. When we encountered questions we did not know the answer to, I divided them amongst the students and gave them the task of finding out the answer for the next lesson. In the next lesson, I related the students' experiences with the snail to the way biologists work and to general characteristics of life. Using the building-block model, the lesson can be typified as follows: <ul style="list-style-type: none"> <li>• Representation form: more genuine materials.</li> <li>• Teaching-learning process: motivate → ask questions → find answers → explain → apply.</li> </ul>
<b>Rules of thumb derived from success experience(s)</b>	<ul style="list-style-type: none"> <li>• Use genuine materials.</li> <li>• When introducing a new topic, give a brief introduction and then let students formulate question themselves.</li> </ul>
<b>Hindrances for application of these rules of thumb in a problem situation</b>	Grade 11 students might ask all sorts of questions that are beyond the scope of the program and/or that I cannot answer. Possible solutions: (a) for some questions: let students find answers themselves as homework (b) make sure I have sufficient time to find answers myself.

Table 6: Formulating rules of thumb by reflecting on a problematic experience using relevant success experiences (continued)

<b>Resolutions</b>	In the near future, I am going to introduce the eye in grade 11 using real materials (their own eyes). In the second half of the lesson, I will let students formulate questions about the eye themselves, I will collect the questions and will base the preparation of my next lesson about the eye on these questions.
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**Phase 4: Toward a generic building-block model with a domain-specific complement**

There was an additional reason for the research question of Phase 4. Inspired by the building-block model for biology, many subject-specific method teachers at ICLON developed their own domain-specific building-block models (see ICLON (2009) for an overview). When these models were examined in more detail, it turned out that whereas the domain-specific perspectives did indeed differ substantially for each subject, the building blocks for goals, instruction, and representation showed many more similarities than anticipated. These findings strengthened our expectation that it would be possible to develop more general building blocks.

For the formulation of generic building blocks for goals, we used the revised version of Bloom's Taxonomy of Educational Objectives (Krathwohl, 2002). In the taxonomy, objectives are framed in terms of type of knowledge (see Figure 2 'content'), and what is expected to be done with that content (see Figure 2 'objectives'). For a general classification of different representation forms, we drew on Gardner's classification of multiple intelligences. Gardner (1999) characterizes different types of intelligence on the basis of the respective representation forms (Figure 3 the 'representation' building blocks). In the model, however, this division of representation forms was used without suggesting that the forms actually each refer to different forms of intelligence, which would be a disputable claim. Finally, on the basis of a literature study and a Delphi study amongst the subject-specific method teachers, new building blocks for teaching-learning processes were formulated (see Figure 2 'teaching-learning process') (Janssen, 2010; Dam et al, 2013). In the formulation of the teaching-learning processes, the 'whole task first' principle was a leading principle, as it is a principle that is shared by almost every modern teaching approach (Merrill, 1999; 2009; Janssen, 2012). The domain-specific complement consists of the perspectives on the subject matter, in this case biology (see Figure 2 'content'). Together, the generic and domain-specific building blocks and the control criteria for the effective combination of building blocks constitute a theory on possible, practical, and effective choices about what and how to teach: Teaching-repertoire Theory.

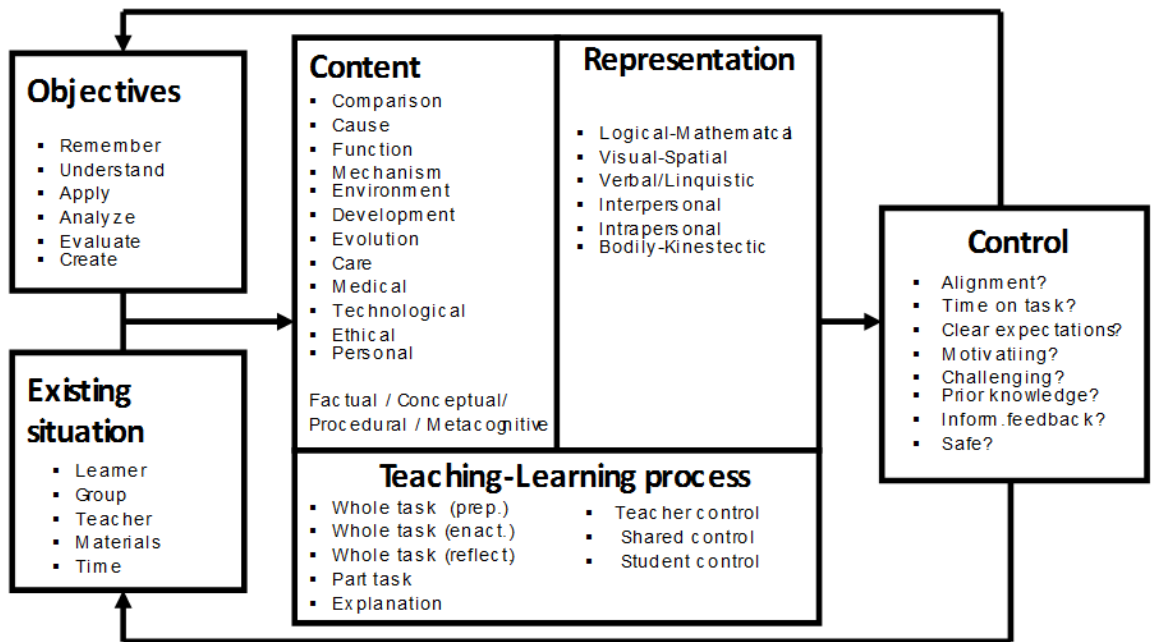


Figure 2: Generic building-block model with a domain-specific complement

Various studies have explored how the building-block model, or specific parts of the model, can be used for different purposes and for different target groups (Aarnik & Vletter, 2010; Schoester, 2010; De Boer et al, submitted; Dam et al, 2013; Janssen et al, 2013). These studies all show that the building blocks stimulate teachers of various subjects to add effective teaching approaches to their teaching repertoire, by means of a spiral process of formulating intentions, designing lessons, learning from enactment of lessons, formulating new intentions etc. Although various studies established the practicality of the method for teachers, in a sense this was still a blind spot for teacher educators. We found that rules of thumb played a role in practical reasoning, but did not know how these were connected to each other and to teachers' goals. We still lacked an underlying theory on teacher's practical reasoning, in order to explain and predict what it is about a given innovative teaching approach and the method for developing this approach that makes it practical for a teacher. This resulted in the following research question for Phase 5: *How can a teacher's practical reasoning when designing a lesson be elicited precisely, in order to establish a practical manner to expand teaching repertoire?*

#### Phase 5: Towards heuristic goal systems as representations of behaviour-guiding aspects of practical knowledge

The work of Simon on bounded rationality was used to 'unpack' a teacher's practical reasoning. Already in the 1950s, Simon criticized the still dominant concept in the social sciences that humans make (or at least are potentially able to make) optimal decisions. Simon (1996) shows that in complex, practical situations, optimization is impossible. Human rationality is bounded by three factors: a) a person generally has multiple goals that need to be realized simultaneously; b) alternative actions are generally not readily available but need to be constructed; c) people tend to have a lack of time, capacity and means to construct all possible alternatives and to weigh them up. Many researchers from various disciplines have since explored how people do make decisions in practical situations.

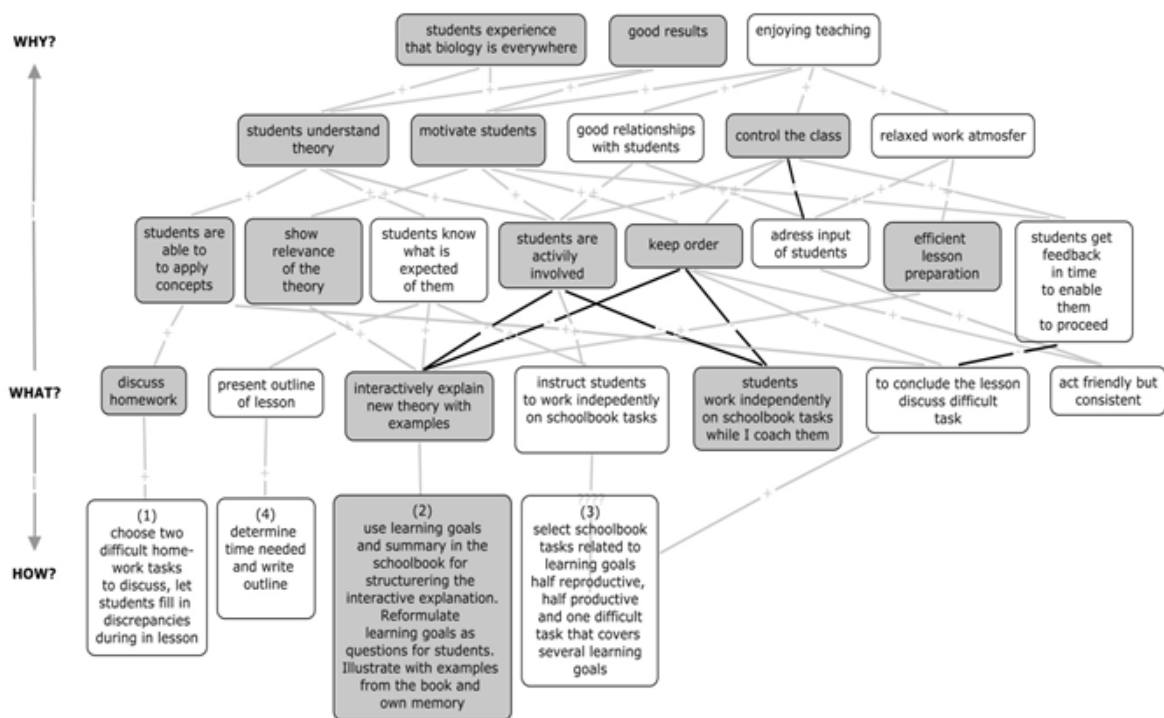


Figure 3: The heuristic goal system of biology teacher Johan

By integrating the practicality theory of Doyle and Ponder (1977) and three general theories on bounded rationality, we developed a theory on teacher decision-making that we refer to as the Heuristic Goal System Theory. The basic premise of this theory is that what a teacher decides is determined by a) his goal hierarchy (Kruglanski & Kopetz, 2010); b) the heuristics he has at his disposal to attain those goals (Gigerenzer & Gassmaier, 2011), and c) the fact that a teacher aims to improve the current situation, rather than optimizing this situation (which would mean maximizing the expected value) (Pollock, 2006). These three theoretical stances led to the development of a heuristic-goal-system methodology, which is illustrated using the case of biology teacher Johan. Johan co-constructed his heuristic goal system (HGS) together with his teacher educator (first author), in order for *both* of them to understand his decisions (practical reasoning) more precisely and to be able to influence his decisions (Janssen et al, 2013) (Figure 3).

First, Johan is asked *what* he does successively in a regular lesson. This leads to a sequence of lesson segments. Next, Johan is asked *why* he thinks it is important or feels the need to include each lesson segment. In this way, Johan's higher goals are elicited for each lesson segment. Next, Johan is asked *how* he prepares for each lesson segment, which leads to a series of heuristics that Johan uses to design his lessons. Finally, Johan is asked to pinpoint which goals and/or heuristics he feels he can fairly easily realize and/or apply (white blocks), and which goals and/or heuristics he is not satisfied about (dark blocks).

A teacher's HGS provides information about what he or she wants to work on. Additionally, by means of an impact analysis, performed by teacher and teacher educator together, it is possible to establish whether a teacher will consider a new teaching approach (new sequence of building blocks) an improvement or not. For this, the new teaching approach needs to be represented as a sequence of lesson segments (building blocks). Together with the teacher, it can now be established which of his goals can be realized using the new approach, and which of his goals are hindered by it. In addition, it can be established which heuristics the teacher already



possesses, and which he will need to develop in order to design lessons according to the new teaching approach. On the basis of this information, a professional development programme can be developed that supports the teacher in recombining or adapting his current lesson segments, step by step, in order to move towards the new teaching approach. On the basis of this information, it is possible to design the programme in such a way that the teacher can perceive each step as an improvement. For each step, a lesson is designed and enacted in class (Janssen, et al, 2013)

The method that emerged in Phase 5 has been used successfully to make several innovations practical for teachers, without losing sight of the core of the innovation. The method has been used in connection with guided discovery learning (Janssen et al, 2013b); context-concept education (Dam et al, 2013); task-based instruction (Janssen et al, 2013); open inquiry labs (Janssen et al, submitted), and adaptive teaching (Janssen, 2012).

## 5. Conclusions

Our long-term design research project has resulted in a practical method, on sound theoretical foundations, that supports secondary school teachers in expanding their teaching repertoire, step by step, to encompass effective new teaching approaches. The main features of the *Model-based Learning from Success Method* are that teachers learn from success experiences and in this way expand their repertoire step by step, building on what they already are able and willing to do. The Building-block Model guides learning from experience as well as the designing of new lessons. The Building-block model is based on *Teaching-repertoire Theory*; the way teachers make decisions using this model in designing, enacting, and learning from their lessons can be described and explained using *Heuristic Goal System theory*.

In this project, theory development was not restricted to the development of generic or domain-specific design principles. We developed two theories with new theoretical constructs that not only help us to explain and predict the effect of our intervention, but that can also be used to explain and predict effects of other interventions aimed at developing a teaching repertoire. Moreover these theories helped us to generate and select other interventions. Both theories were developed by reduction and integration Reduction was a factor in focusing on the underlying components of practical reasoning, in the case of Heuristic Goal System Theory, and the building blocks of teaching approaches, in the case of Teaching-repertoire Theory. Integration came into play when combining many theories into a new theory that overcame the individual weaknesses or incompletenesses of its predecessors. We conclude the present article with an endeavour to explicate the strategy we have used during this design research project to develop these theories. Although the strategy was not consciously applied throughout all the phases, looking back, we can see that it guided our approach in every phase.

- a. Do not be satisfied that something works. Ask yourself why it works (or does not work).
- b. Constantly ask yourself whether your problem is an example of a more fundamental problem.
- c. Search for researchers who are investigating the foundations of this fundamental problem.
- d. Draw inspiration from their solutions, and try to elaborate those solutions (or potential solutions) and theoretical foundations, by applying them more specifically to your specific problem.

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## Designing an Online Learning Environment to Support Group Collaboration: A Design Research Case

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# 37. Designing an online learning environment to support group collaboration: A design research case

Qiyun Wang

## Abstract

*In this study, an online learning environment was created based on an ICT tool to support students' collaboration when they were completing their course group assignment at the National Institute of Education in Singapore. The learning environment was developed and improved by following the educational design research approach. The design of the environment progressed through two stages. A set of design strategies (e.g. small group size, friendship, authentic learning tasks, DriveHQ, progress reports, and product versions) was proposed and tested out with 48 groups in 4 classes in the first design stage. The posts in the environment and student's reflection reports were analyzed. Results showed that the strategies of the use of friendship, authentic learning tasks, progress reports, and product versions worked well but other strategies such as the adoption of small groups and of the ICT tool could be further revised. Revision decisions were made at the end of the first stage and the design strategies were revised and tested out with additional 23 groups in the second design stage. Results showed the revised strategies worked better. This chapter describes the rationale for following the educational design research approach in this study, the conceptual framework for involving the design strategies, and students' perceptions. Design principles and lessons learned from this study are also presented at the end of the chapter.*

## 1. Introduction to the problem

Work becomes more interdisciplinary and complicated in the current knowledge society. It is hardly possible for an individual to complete a complex task without the help of others. Therefore, having the ability to work together becomes increasingly crucial in the present workplace (Barron, 2000). One of the major goals of the third Master Plan for ICT in Education (2009-2014), proposed by the Ministry of Education (MOE) of Singapore is using technology to promote students' collaborative learning (MOE, 2009). Students are advised to start to learn how to work collaboratively when they are studying in schools (Chai, Lim, So, & Cheah, 2011).

The way of simply placing students into groups and asking them to work together does not imply that collaboration will naturally happen. Some design strategies must be applied to promote collaboration. A number of strategies work well in face-to-face classroom settings such as think-pair-share, jigsaw, or role play. But they do not work at all in an online learning environment as they often need people to meet physically. Also, collaborative learning has a number of challenges, such as how teachers know that group members really work together rather than one works for the others; How to fairly assess group members' individual contribution (Johnson, Johnson, & Holubec, 1998); and How to effectively coordinate group collaboration and monitor the collaborative learning process when students are at different places (Pozzi, Manca, Persico, & Sarti, 2007). All these challenges need to be carefully addressed in collaborative learning processes.

Technology is not a panacea. However, it has great potential to address some of the above challenges (Wang, 2010). For instance, when students are at different places, they can use technology to share information and communicate with their group members. Also, their collaborative processes may be automatically recorded, which enables group members to trace their progress and also allows the teacher to identify their individual contribution. However, in spite of the above potential, there is little empirical research that has shown how technology could be effectively used to support collaborative learning, in particular, to coordinate and monitor the learning process.

A research study was therefore initiated in the context of a teacher training institute in Singapore by following the design research approach. The main purpose of the study was to provide an online learning environment where students could coordinate their collaborative effort when they were completing the final assignment of a course in groups. The assignment was to design an ICT-based learning package in a form of web sites or PowerPoint slide in a period of six weeks. Also, the teacher could monitor students' collaborative processes and individual contribution by accessing the environment. To meet these purposes, a set of design strategies and ideas for coordinating and monitoring students' collaborative learning was tentatively proposed based on the review of literature at the beginning of the study.

The study reported here is a validation study in nature, aiming to test if the design strategies embedded in the online learning environment could help to coordinate and monitor group collaboration. Also, the study is a development study, aimed at solving the problems involved in coordinating and monitoring the collaborative learning process. The focus of this study was on investigating this set of strategies as an end in itself (the characteristics of workable strategies), rather than as a means towards the end (the effect of strategies on the learning outcome).

By following the design research approach, this study progressed through two main phases: a preliminary research phase and a design and piloting phase. In the preliminary research phase, a body of literature was reviewed and some strategies were proposed. During the design and piloting phase, two rounds of iterative design were carried out at the National Institute of Education (NIE), Singapore, and some effective strategies for coordinating and monitoring the collaborative learning process were identified.

The structure of this chapter is as follows. The conceptual framework for designing an online learning environment in which certain design strategies were involved to support group collaboration is presented in the following section. This is followed by two design stages. In each stage, the context, design strategies used to coordinate and monitor the collaborative process, evaluation questions, major findings, and revision decisions are described. The last two sections summarize the yield of the study in a form of design principles and lessons learned.

## **2. Conceptual framework**

This section presents the conceptual framework for this study. First, it differentiates collaborative learning from cooperative learning by highlighting that collaborative learning is the focus of the study, and then describes the key concepts - individual accountability and positive interdependence - of collaborative learning. This is followed by challenges involved in collaborative learning and discussion on the possibility of using technology to address the challenges.

### **Cooperative learning and collaborative learning**

Although cooperative learning and collaborative learning are often used interchangeably, they are slightly different (Chai & Tan, 2010). Cooperative learning often means that a task is divided into different parts and each part is taken by an individual member. Everyone is in charge of a separate part and in the end all completed parts are assembled together and the whole task is completed. In a cooperative learning process, individual group members may not communicate and interact with others. They solely focus on their individual parts of the task. They also seldom help the other members or learn from the others. By cooperation, their individual workload is often reduced and the task is completed in a shorter time period.

Compared to cooperative learning, collaborative learning is a step further. In addition to dividing the task into different parts, group members share information with each other, discuss ideas, and negotiate meaning with their group members (Lipponen, Hakkarainen, & Paavola, 2004). They do not concentrate on their own parts of the job only, but support the others and learn from other members. It is more of an on-going process, in which all group members work together and support each other (Bruffee, 1999). In this study, the students were expected to involve collaborative learning rather than cooperative learning.

### **Key concepts of collaborative learning**

Individual accountability and positive interdependence are two pillars of collaborative learning (Wang, 2009). Individual accountability is the measure of whether the contribution of each group member has helped to achieve the group's overall goals (Johnson, et al., 1998). Ideally, each individual plays a certain role in group work and makes equal contribution to the entire group work. Each individual is accountable for his or her share of the work.

Research shows that many strategies can be used to promote individual accountability. For instance, making the learning task meaningful is a useful strategy as it enables group members to see the value of the learning task and its relevance to their needs (Arvaja, Häkkinen, Eteläpelto & Rasku-Puttonen, 2000). Friendship is another useful strategy. Friends are often socially and positively bonded, and hence they do not need to negotiate the rules of collaboration. They have built ways of working which are implicitly understood rather than explicitly discussed (Vass, 2003). As a result, they are often more willing to interact with peers, and the atmosphere is more open and friendly (Damon & Phelps, 1989).

Positive interdependence links group members together in a collaborative learning environment. The contribution of each individual is counted and important for the success of the work. Group members help one another to get the task completed. In a positively interdependent learning environment, one cannot succeed without the support of others; they either sink or swim together (Johnson, et al., 1998).

Research shows that keeping a good working relationship within a group helps to promote and maintain positive interdependence (Kirschner, 2002). Other strategies such as rewarding the whole group when they achieve certain progress or distributing different resources to different members can also foster positive interdependence (Brush, 1998).

### **Challenges in collaborative learning**

Coordinating group members' collaborative effort and monitoring the collaborative process are salient challenges in collaborative learning. Group members often need to identify and build on their individual strengths so that everyone makes a fair contribution to the learning task (Land & Zembal-Saul, 2003). Also, their individual effort must be synchronized to ensure that they all work towards the same direction and make coherent contributions, so that the work can be completed in an efficient way (Hämäläinen, 2008).

Meeting face-to-face is often an effective strategy for coordination. However, the challenge is that people are often difficult or it is too expensive to meet in person if they are at different places. Also, people may not be able to reach a consensus during a short meeting as some of them may have not been well prepared for the topic to discuss (Wang & Woo, 2007). In addition, a decision made during a face-to-face meeting might be biased as some members may not have an equal opportunity to voice their opinions up or the meeting may be dominated by a few vocal participants.

Learning is a highly interactive and dynamic process. From the students' perspective, keeping track of what has been established and what needs to be further revised makes the learning process be carried out in a more organized and efficient way. From the teachers' perspective, monitoring the learning process allows them to identify strengths and weaknesses of the instructional design or the learning environment so that they can adjust the learning process promptly (Pozzi, et al., 2007). Also, monitoring the learning process enables teachers to assess students' individual and group learning more accurately.

However, effectively monitoring the collaborative learning process is also a challenge. Monitoring the learning process requires detailed information about what is going on and how students work collaboratively. On the other hand, it should not force students to carry out excessive work just for the purpose of monitoring the learning process. Ideally the learning process should be automatically documented without students making additional effort.

### **Technology support for online collaborative learning**

Technology plays an increasing role in education and it also has great potential to address the abovementioned challenges. Students may use online chatting tools such as MSN or Skype to communicate with their members free of charge. But the limitation of using synchronous chatting tool is that users must be available at the same time. Alternatively, they can use asynchronous tools such as a discussion forum or Google groups to share information. Similarly, the limitation is that students may not be able to communicate and get responses immediately.

A more effective way to facilitate coordination by using technology would be to integrate the strengths of various communication tools if a single tool cannot afford all the required functions. By using a combination of the tools, students in groups can interact with other members in a convenient way, either synchronously or asynchronously. In this chapter, the online learning environment refers to a virtual space hosted by a web-based ICT tool but enhanced by integrating additional ICT tools if needed.

For monitoring the collaborative learning process, technological tools such as wikis or discussion forums can automatically record the process of their interactions and this record would enable group members and the teacher to trace and monitor students' collaborative learning activities and processes. But the challenge with monitoring the collaborative learning process is that some evidence may not be recorded down if the students are not using the environment at all (Hämäläinen, 2008). For instance, students may discuss ideas in face-to-face meetings or using mobile phones. In such cases, the online learning environment will not be able to trace the discussion process.

### **Research question and design guidelines**

The main research question of the study was: *What are the characteristics of an effective set of design strategies for coordinating and monitoring the collaborative learning process in an online learning environment?*

Based on the reviewed literature, the following guidelines for designing the online learning environment were initially formulated:

- The learning task involved in the assignment must be meaningful to the students;
- Groups are formed based on friendship;
- ICT tools must be used to coordinate students' collaboration;
- The environment must enable the teacher to easily monitor the collaborative learning processes of group members.

The following sections will describe the two design stages involved in the prototyping phase, and describe what design strategies were used in each stage and how the participants perceived the strategies. Feedback was collected from the participants and revision decisions on strategy adjustment were made at the end of each stage. More detailed descriptions of the two design stages are published in Wang (2009, 2010).

### 3. Design stage 1

This section presents how the first design stage of this study was carried out. It first depicts the context in which the study was initiated, and then describes the research questions and major findings. Revision decisions based on the findings are listed at the end of this section.

#### Context

An online learning environment was designed to facilitate students to collectively complete the final assignment in the course entitled *ICT for engaged learning* at NIE. These students would become Primary or Secondary school teachers after graduation. This course was a core module, which ran once a week of two hours each and lasted for 12 weeks. All tutorials were conducted in computer labs.

The final assignment of this course was as follows. The students in pairs were to design an ICT-based learning package in a form of web sites or PowerPoint slides. This assignment had to be completed within six weeks, during which the students had face-to-face tutorials as usual. This assignment carried 60% of the final marks. There were a total number of 56 classes of about 24 students each in that semester. A number of 48 groups (each comprising of 2 students) from 4 classes, which were taught by the Wang, participated in this round of the study. For administrative purposes, the members of each group were from the same class. Table 1 lists the strategies students followed - as a meal rather than a menu (Fullan, 2007) - when they were completing their group assignment.

Table 1: Design strategies used in this stage

Strategies	Description
Friendship	Rather than the instructor assigned students into different groups, each student was allowed to choose a friend from the same class as a partner for this assignment. Most but not all groups managed to pair up with their friends.
Meaningful learning tasks	To make the learning task more relevant to them, each group was encouraged to choose a topic from their mutual subjects such as Physics or Math for the final project.  They were required to design learning resources in a form of learning package for school students rather than themselves to learn the topic.

Table 1: Design strategies used in this stage (continued)

Strategies	Description
ICT tool: DriveHQ	<p>The online file storage and sharing tool DriveHQ (<a href="http://www.drivehq.com">http://www.drivehq.com</a>) was used to facilitate collaboration. It provides each user with a free space, in which he or she can create folders, and upload and download files.</p> <p>It allows invited friends to share folders or files, and make comments. These features make DriveHQ to be a useful tool for collaboration.</p> <p>Each student had an account with the tool, and each group had a shared folder for file sharing with its members and the teacher.</p>
Progress report	<p>It included three parts: activities, rationale, and comments. The student who had just made a major revision informed the other member what changes (tasks) had been done, why these changes had been done, and what further activities ought to be carried out later. This was done individually.</p> <p>It enabled group members to coordinate their collaboration, and also allowed the teacher to monitor their progress and individual contribution.</p> <p>Each group was encouraged to post their progress reports once a week. However, no marks were rewarded for writing progress reports.</p>
Product versions	<p>Each group was encouraged to save every major product version they had produced in a separate folder in the shared space.</p> <p>They were advised to add the date of completing the version (such as '26 Aug 2007') or a serial number (such as version 1 or version 2) to the name of the folder.</p>

### Evaluation questions and instruments

This round of research aimed to answer the following questions:

- Did the strategies promote group collaboration in terms of coordinating and monitoring the collaborative learning process?
- Was the online learning environment hosted in DriveHQ useful for facilitating collaboration?

For answering these evaluation questions, both quantitative and qualitative data were collected. The quantitative data included the numbers of progress reports and product versions created in the online environment by each group. The qualitative data were obtained from students' reflection reports. At the end of the course, the students were required to submit a short report about 200-300 words as part of the final assignment to reflect on how often they used the strategies, how useful the strategies were, and what problems they met when they were using the online environment.

For data analysis, the numbers of progress reports and product versions were counted. Also, each student' reflection report was carefully read through, and relevant information related to each research question was highlighted and tagged with corresponding design strategies.

## Major findings

### ***Did the design strategies promote group collaboration?***

Based on the reflection reports, it was found that more than 90% of the students worked together as a group in the process of project development. They helped each other and also learned from their peer. The weekly progress reports posted to the online environment also confirmed that they regularly communicated with each other and get the assignment done gradually. Their group collaboration also heavily depended on their individual strengths and contribution.

They reported that communication and understanding were critical factors that affected collaboration within groups. Sometimes their partners might not be able to fulfill their promise due to some unforeseen reasons, they attempted to understand them. They also felt they learned how to share, discuss, reach consensus, and respect others when they had different opinions.

They felt that the strategy of friendship enabled them to carry out the final assignment smoothly. On the other hand, working on the group work also provided an opportunity for them to build and enhance friendship. Many of them became good friends after completing the final project even though some did not know each other very well at the beginning.

The students liked the strategy of choosing meaningful learning tasks. They felt that the artifacts developed for the assignment could be further used in their future teaching. Also, they could choose a topic they liked.

Completing progress reports required them to specify tasks and roles explicitly, which got them identifying their individual duties and responsibilities. It also compelled them to write down the rationales and to articulate why their artifacts were designed in such a way. They felt that writing progress reports enabled them to plan and organize their developmental processes in advance. By using the progress report, they could easily keep track of what had been done and what needed to be carried out further.

The use of product versions enabled group members to monitor how the final product was gradually developed. In addition, by checking the product versions and dates attached, the instructor could easily identify the progress of the final project.

However, results also showed that many groups did not use the online learning environment sufficiently to collaborate. About one third of the groups (n=15) did not submit any progress reports and about half groups (n=26) only uploaded their final version of their assignment to the online environment. A few students (n=5) reported negative experiences regarding the use of progress reports. They mentioned that completing progress reports for a small group of two members was rather redundant. In addition to this course, they also had other courses conducted in face-to-face manners. Everything could be easily decided during face-to-face meetings. Or, they could use mobile phones to communicate. They felt that writing a progress report was an extra work to them.

### ***Was the online learning environment hosted in DriveHQ useful for facilitating collaboration?***

Students found that the use of DriveHQ allowed them to backup files. They could easily upload and share files with their group members. In addition to the specific copies on their own

computers, the copy on DriveHQ was an additional backup. Keeping an additional copy on the Internet enabled them to easily share and meanwhile they felt safe.

In addition to sharing files, the other member could also give comments to specific files or folders. These comments often served as useful information for them to know what the files were about, or what changes were made.

However, the students encountered some technical problems with the tool. They commonly indicated that the communication function was insufficient. It did not support synchronous chats or asynchronous online discussions. Also, some students mentioned that they had some difficulties with uploading file folders. Consequently, they had to upload files one by one, which was inconvenient and causing a lot of troubles.

### **Revision decisions**

This round of research showed that forming groups by friendship enabled students to maintain a warm atmosphere and close working relationship. For those students who were not friends at the beginning of the assignment, they also reported that completing assignments in groups helped to build a sense of friendship among group members. Making learning tasks meaningful enabled them to see the relevance of the task to their future teaching needs. In addition, the strategies of producing product versions, writing progress reports, and the use of DriveHQ helped to coordinate and monitor group collaboration to a certain extent.

However, the result also showed that this round of the study had some limitations. For the groups who seldom used the online environment to collaborate, no evidence showed that these groups worked collectively. Nevertheless, their reflection reports submitted as part of their assignment indicated that they actually worked together on the project. They used other ways such as face-to-face discussions, email or phone calls to coordinate. This finding implied that the design strategies used in this round did not fully capture the collaborative learning process. Additional strategies were needed to more comprehensively catch collaborative evidence in the following stage.

As some individuals complained that writing a progress report was an extra work for them, the second round would give them an option to decide whether they reported progress or not. Writing progress reports became an item of a menu rather than a course of a meal (Fullan, 2007). Also, they would be given more flexibility to write, either individually or in groups. Regarding the product versions, if the ICT tool could record down sufficient evidence, they would not need to provide extra product versions.

The students also reported some limitations regarding the use of DriveHQ as a supporting tool in this round. Its communication function was weak. It did not support synchronous chats or asynchronous online discussions. As the users could not create discussion forums inside, they had to communicate through face-to-face discussions, Skype or email. The way of communication in DriveHQ was not natural. Therefore, the ICT tool used to support group collaboration needed to be revised in the following round.

As mentioned above, using an online environment to support the collaboration of a small group of two members was not that effective, as they could easily communicate via phone calls or meetings. The following round would involve a bigger group size. Based on the findings and revision decisions, the second design stage continued. The following section will describe the strategies used in the second design stage and the feedback collected.



## 4. Design stage 2

The second design stage was initiated based on the revision decisions made at the end of the first design stage. This section describes how the second design stage was implemented. It starts with a description of the context, followed by research questions, instruments, and major findings. Also, ideas for future improvement are suggested at the end of the section.

### Context

This stage was conducted in the same course in the following semester. The total number of students taking this course in the semester was about 1100. They were divided into 37 tutorial classes of about 30 students each. All classes followed the same assessment criteria for the assignment. A total number of 23 groups of four members in four classes taught by the Wang participated in this round.

The final assignment was to design an ICT-based learning package, which was the same as that in the first stage. But for this round, the students were in groups of four rather than of two to complete their group assignment. Table 2 lists the main strategies used in this round to promote students' collaborative learning. The design strategies for grouping and choosing an ICT tool were not newly added to this stage, but the way of implementing the strategies was revised as described in Table 2.

*Table 2: Design strategies used*

Strategies	Description
Grouping	Bigger groups: in groups of four
ICT tools	They could choose any tool they wanted. Four tools were recommended: drop.io, Google Group, Wiki, and Facebook group
Same strategies as that in the first stage	Friendship Meaningful learning tasks Progress report: optional; could be written individually or as a group Product versions: optional; they would not need to provide product versions if the environment could record down sufficient details

The students were encouraged to use online tools as much as possible to communicate. The students were informed that if the online environment had already automatically recorded their interactions, they did not need to prepare an extra progress report. The use of the progress report aimed to supplement what was missing or not recorded in the workspace. Also, the product versions were optional. They could decide if they uploaded files to the online environment. The focus of this round of the study was on providing a natural and convenient online space where students could collaborate with their members.

### Evaluation questions and instruments

This round aimed to answer the following research questions:

1. How did the students support and coordinate their group collaboration?
2. Did the use of the online environment enable the teacher to monitor the collaborative learning process and assess students' individual contribution?

As this round intended to find out how the group members actually coordinated their collaboration by following the strategies and if the evidence (such as posts) recorded in the online environment enabled the teacher to monitor the collaborative process, the evidence of

students' interactions recorded in the online learning environment was the main data source. Therefore, the major instrument used for data collection was the posts in the online environment. The posts showed the resources that students shared, the messages they exchanged, and the files they produced. Another instrument was the progress report uploaded to the online space, which was to identify how group members coordinated with one another and how the final assignment was completed gradually.

The analysis of the posts was as follows. All entries were sorted out in a chronological order. The numbers of notes and files in each group were counted. The entries were browsed through to check if they were posted on different days, which implied if the groups used the environment regularly and frequently. When a note or file was read through, it was tagged with certain keywords such as reporting progress or sharing web resources. Meanwhile, the flow of completing the final assignment and the ways of writing progress reports were summarized.

## **Major findings**

### ***How did the students support and coordinate their group collaboration?***

Three levels of collaboration were found on the online environment: progress reporting, one-way information sharing, and two-way interaction. On the level of reporting progress, group members reported what they had done individually or as a group, and what they were going to do. They just posted their progress reports online, but did not further share other resources or ideas. On the level of one-way information sharing, group members shared resources and reported their progress online. But very few comments were posted to the environment and no two-way interactions were found. What they did was only one-way information sharing. On the level of two-way interaction, group members extensively shared resources, negotiated meanings and discussed ideas.

Five groups were at the progress reporting and one-way information sharing levels respectively, and 13 groups were at the two-way interaction level. The groups at the two-way interaction level did not only post their progress reports or learning resources online, but also gave feedback or comments. An obvious indicator of having interactions in these groups was that group members often invited responses from other members by addressing their names. Comparatively, on the two lower levels of collaboration (progress reporting and one-way information sharing), group members seldom invited others for comments.

Altogether 14 groups explicitly put their progress reports to show what they had done in the previous week, what they were going to do in the following week and what roles they were going to play.

Although the students were not required to use MSN or other chatting tools to communicate, 3 groups used MSN to chat and put chatting records to their workspaces. Four groups used the discussion forums in Facebook Group or Wechat to discuss ideas and coordinate their collaboration. But the groups using Facebook Group commonly reported the limitation of Facebook Group that it did not allow users to share files in formats of DOC, PPT or PDF. In addition, completing this assignment did not require them to specify leaders, but posts on the online spaces showed that a few groups naturally evolved leaders along the project progress. In addition, all groups in the classes heavily used face-to-face meetings and progress reports to coordinate their collaboration. 15 groups had face-to-face meetings. Some of these groups used the online environment to negotiate when and where they would have face-to-face meetings.

***Did the use of the online environment enable the teacher to monitor the collaborative learning process and assess students' individual contribution?***

The use of the online environment in this study revealed how the final assignment was gradually completed. The sequence of the posts in the online environment indicated that the process of completing the final assignment among the groups was similar. All groups started with topic selection, which was followed by task distribution and individual commitments.

In addition, the use of the online environment and progress reports helped the teacher to fairly assess students' individual contribution. By looking at the resources, notes, and comments in the workspaces, the teacher could identify what each member had done for the assignment.

**Ideas for future revision**

The result showed that more groups in this round actively used the online spaces to support two-way interaction. But about half of the groups used the spaces for reporting progress and one-way information sharing only. It seems that additional strategies are still needed to promote more active use of the online environment for interactive collaboration. One possible strategy can be giving them additional bonus marks for online participation. This would be further explored in future research.

Writing progress reports seemed to be an effective strategy to coordinate group members' collaborative effort and monitor the learning progress. However, students should be clearly informed that writing progress reports is not solely for the teacher to track their progress, but mainly for them to summarize and reflect on what they have done. Otherwise, students might be reluctant to do it.

In addition, this round of research also found that writing progress reports individually might create a tension between group members, as some members reported every detail but actually did less than others. How to write a group's progress report needs to be further studied in future research. Peer evaluation might be an additional useful strategy to judge individual contribution, which has not been explored in this study yet.

The result showed that the face-to-face meeting was commonly adopted by many groups in this round. Having opportunities to meet face-to-face might reduce the level of necessity for using an online environment to collaborate in the study. Future studies would involve students who are located at different places and have fewer opportunities to meet physically. In this case, using an online environment to support collaboration may therefore become more essential.

**5. Yield of the study**

According to Van den Akker (1999), design research has two major purposes: product improvement and knowledge growth. Knowledge growth is usually presented in design principles in a form of heuristic statements like 'If you want to design curriculum X (for the purpose/function Y in context Z), then you are best advised to give that curriculum the characteristics A, B, and C (substantive emphasis), and to do that via procedures K, L, and M (procedural emphasis), because of theoretical and empirical arguments P, Q, and R' (p. 9). In this section, the yield of the study will be presented in design principles by following this format.

The overall general design principle summarized from this study is: If teachers want to design online learning environments for the purpose of coordinating and monitoring the collaborative learning process, they are best advised to involve the following design strategies in the environment:

*Using an online learning environment to support group collaboration may be effective only when the group size is reasonably big.* In the first round, students completed their assignment in groups of two. The students indicated that they could easily communicate by using mobile phones, emails, or in face-to-face meetings. They were reluctant to use an online space to share and interact. During the second round, the group size was increased to four. As a result of this together with other strategies, a higher percentage of groups used the online environment to support collaboration. However, this study did not address the question of how big a group should be for effective collaboration to take place.

*Strategies must be applied to stimulate and encourage students to use an online environment.* Providing an online space does not mean students will automatically use it (Hämäläinen, 2008), particularly when the group size is small or the online environment is new to them. Allowing them to choose any tools they like - such as wikis, Facebook, or Google groups - seems to be a helpful strategy to promote frequent use of the tool or the environment. At least they have fewer technical difficulties when they are using a more familiar tool. In the second round of the research, a higher percentage of groups used online spaces to collaborate, partly because they could use any tools they liked to support their communication.

*An online learning environment must support both synchronous and asynchronous forms of communication.* In addition to sharing files and giving comments in an asynchronous way, some groups also used instant messaging tools like MSN to chat with their members. It seems that synchronous communication is crucial for collaboration as students can share information and get feedback immediately. This study found that both synchronous and asynchronous forms of communication should be involved in an online learning environment so that students can conveniently communicate with each other.

*The importance of face-to-face meetings cannot be compromised.* Many groups chose to sit together to discuss even when online communication tools were available. It seems that face-to-face meetings have certain unique features over other communication forms and students prefer to meet physically if they have such opportunities. A learning environment should hence provide opportunities for students to meet personally if possible.

*An online environment is preferable to support files in different formats.* In addition to supporting different forms of communication, an online environment is expected to support files in different formats. At the time of the study, Facebook Group only supported picture or video files but did not support files in the DOC, PPT, or PDF format. When they chose using Facebook Group to collaborate, they had to use other tools to support file sharing, which was quite troublesome as they had to shift from one program to another. An online space would be more useful if it can support various formats of files.

## **6. Reflection**

This study shows that design research is a useful research approach for approximating an optimal solution to an educational problem. Coordinating and monitoring the collaborative learning process is an educational problem in this study. Tentative strategies for solving the problem were proposed at the beginning of the study. However, whether these strategies would work or not was hard to decide. Through two rounds of the design research process, the strategies remained were most likely to have higher potential to address the problem. This study demonstrates that design research is a refining process to identify and testify an optimal

solution 'until a satisfying balance between ideal ('the intended') and realization has been achieved' (Plomp, 2010, p. 13).

Meanwhile, design research is also a convincing approach to explaining why the solution to an educational problem is optimal. Compared to other research methods like survey or evaluation research which often just describe the final result or compare the results of a pre-test and a post-test but without giving a detailed justification for the use of an intervention, design research is more process-oriented (Plomp, 2010). It documents the research process by designing an intervention, testing it out, collecting data, analyzing data, and revising the intervention (Van den Akker, 2010). The whole iterative and spiral process records and demonstrates how the final solution gradually emerges. Theoretically, this may not be the best solution, but it is most likely to be the optimal one in a real context given certain conditions.

In addition, involving in design research seems to be a useful learning journey or a professional development process for practitioners. Plomp (2010) summarizes three major outputs of design research as follows: design principles, optimal interventions, and professional development of practitioners. The first two outputs are related to knowledge growth and product improvement (Van den Akker, 1999). According to Plomp (2010), 'the participation of practitioners should also be seen as an important form of professional development' (p.22). In this study, the practitioner was also the researcher. Conducting the design research was obviously a learning journal for the researcher. By doing literature review in the preliminary research stage, the researcher learned what learning theories or design strategies could be used. In the prototyping stage, the researcher linked the theories into practice and produced 'usable' knowledge.

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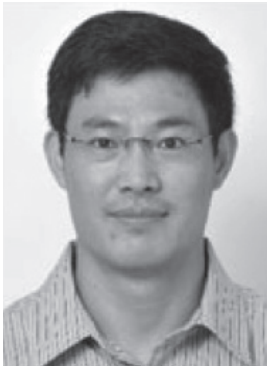
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## Design and Development of an Online Version of a Special Educational Needs Master's Program

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# 38. Design and development of an online version of a special educational needs master's program

Anneke Smits, Joke Voogt & Jan van den Akker

## Abstract

*This case study describes research that aimed at transforming four face-to-face Master Special Educational Needs programs to e-learning. The study was conducted according to the principles of design research and consisted of three phases: the analysis phase, the pilot phase and the implementation phase. The analysis phase included a contextual needs analysis, a literature review and a consultation of three e-learning experts. This phase resulted in a description of four clusters of design: interaction between students, structure, teaching behavior and learning materials. These clusters each contained several design principles. In the pilot phase data collection and analysis were primarily qualitative in nature. Based on the findings in the pilot phase the design principle 'synchronous office hours' was dropped. In addition to this several revisions were made to the practical aspects of the design principles. The implementation phase took almost two years. In this phase 15 instructors were involved as well as two cohorts of students, 77 students in total. Data collection and analysis were both quantitative and qualitative in nature. The remaining design principles proved to be usable and effective after several revisions at the practical level. The study yielded design principles that may prove useful in comparable, competency-based, forms of higher education.*

## 1. Introduction to the problem

This study took place within the Windesheim master's program for Special Educational Needs (SEN). Windesheim is a Dutch institute for higher education and the master Special Educational Needs is part of the Windesheim School of Education. In 2005 the management team of the Windesheim master SEN commissioned the design and production of four master SEN programs via e-learning in order to raise the number of student enrollments in the program. The subjects of these master's programs were 'Remedial Teaching' and 'Language and Dyslexia' for primary and secondary education. Most of the students work as teachers. All four master SEN programs had existed for some time in the form of face-to-face courses. The 2-year part-time programs showed considerable overlap in terms of courses. In total 11 different e-learning courses were produced, all of which develop specialized teacher competencies. In all courses knowledge, skills and (subconscious) professional beliefs are integrated objectives. Students learn to solve authentic complex problems in professional practice.

The e-learning assignment from the management team contained goals in terms of numbers of enrollments, student satisfaction and academic success for the e-learning courses. Within the Windesheim institute there was no prior experience with e-learning. The conversion of the four programs therefore constituted a major challenge. A small e-learning team was formed. The team consisted of a manager, a researcher (first author of this article) and two lecturers. Near the end of 2005 a rough draft of the e-learning design for the entire program was delivered, primarily based on a study of four influential books on e-learning pedagogy (Bender, 2003; Collison, Elbaum, Haavind, & Tinker, 2000; Duffy & Kirkley, 2004; Hiltz & Goldman, 2005) and

on the team's earlier experiences with asynchronous discussions in blended learning. In response to the rough draft, questions were raised by the Windesheim management about the design. Basically the management had hoped for a much simpler and cheaper solution, cheaper in terms of both course development and instructor involvement. They also wondered whether the design would be attractive for students.

In response to the doubts that were expressed by the management, the current study was initiated. The purpose of the study was to validate and refine the rough draft of the e-learning design, and to support and evaluate the implementation. Furthermore the study sought to contribute to the scientific knowledge base about e-learning with a validated set of principles for e-learning design. The problem statement in this study was as follows: Which principles constitute a valid, usable and effective e-learning design for master SEN courses? Validity of the e-learning design means that the design is partly based on recent scientific findings and on the knowledge and experience of experts in the field. The word usable refers to design features that are feasible and useful for students and teachers (see Doyle & Ponder, 1977). In order for the e-learning design to be effective, it is important that it does not generate increased dropout rates as compared to regular courses, that it enables students to acquire the necessary skills at the master level and that the level of student satisfaction is at least comparable to the satisfaction in the regular program.

The problem statement resulted in the following research questions:

1. What is a suitable design for the master SEN e-learning courses?
2. Do the design principles (based on the validation of a rough design by means of literature and interviews) turn out to be usable for both students and instructors in the setting of the Windesheim master SEN? Which changes are needed?
3. Do the design principles lead to effective master SEN courses in terms of student satisfaction and academic results?

The study was conducted according to the principles of design research (Van den Akker, 1999; Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; Dede, 2004; McKenney, Nieveen, & Van den Akker, 2006; Nieveen, 2009; Plomp, 2009; Richey & Klein, 2007; Shavelson, Philips, Towne, & Feuer, 2003). This research approach was chosen because no ready-made solutions were available. The original rough design had to be refined and translated into new practice. Design research is ideally suited for situations in which new interventions are developed. In design research there is a close relationship between theory and practice and a cyclic approach to design, implementation, evaluation and revision. It was through this cyclic approach that the questions of validity, usability and effectiveness could be answered whilst further developing the new intervention in a research based fashion.

The study consisted of three phases: the analysis phase, the pilot phase and implementation phase. The analysis phase took 1.5 years. The pilot phase lasted six months. The implementation phase covered a period of almost two years, in which two cohorts of students were followed. Data collection was rich; several methods were used: interviews, surveys, field notes, collection of forum contributions and of other documents relating to e-learning and to the educational concepts of the program. Data were analyzed quantitatively with SPSS and qualitatively with QDA Miner.

The analysis phase will be discussed in the second section of this chapter. The pilot phase and the implementation phase will be the subject of the third section of this chapter. The fourth

section of the chapter will discuss the effects of the e-learning implementation. The fifth section will describe the yields of the study, whereas the sixth section will contain a reflection on the lessons learned.

## **2. The analysis phase of the study**

The first research question was central to the analysis phase of the study: What is a suitable design for the master SEN e-learning courses? This research question was answered on the basis of contextual needs analysis, literature review and expert consultation.

### **Contextual analysis**

The contextual needs analysis was carried out on the basis of document analysis and three semi-structured interviews with important stakeholders from Windesheim.

Document analysis focused on Windesheim documents pertaining to pedagogy and assessment in the master SEN as well as project plans regarding digital education. The analysis resulted in a list of goals and limitations for the e-learning design. Short term goals were: expansion (a minimum of 30 new e-learning students), academic success (comparable to the face-to-face courses), and student satisfaction ( $\geq 7$  on a scale of 1-10). The most important educational constraints were defined by the documents pertaining to pedagogy and assessment in the master SEN. Goals, content, pedagogical principles and the assessments of the face-to-face courses were to be used, while adding new principles needed for effective delivery via e-learning. The institution had mandated that the design of the e-learning courses had to adhere to the following core principles of the face-to-face courses: social constructivism, skills development, authentic learning and autonomous learning. The semi-structured interviews with the stakeholders revealed financial and organizational constraints. Furthermore the stakeholders emphasized the importance of usability for students and the importance of intensive support for e-learning students, both before and during the e-learning experience.

### **Literature review**

The purpose of the literature review was to validate or to reject design principles of the original rough design. For the literature review electronic databases and catalogs of the University of Twente were used. In addition Google Scholar was used which contains an increasing number of accessible and searchable articles.

The literature review resulted in a grounded description of four clusters of design principles for e-learning: (1) the interaction among students, (2) the structure, (3) the instructor's role, and (4) the course materials. Within the four design clusters a total of 15 design principles were identified and described for the e-learning courses. These principles are named in table 1. In the literature review each of the principles is carefully defined and scientifically substantiated whereas practical aspects are also mentioned. The four design clusters were primarily based on literature about collaborative learning (Cohen, 1994; Dillenbourg, 1999; Gokhale, 1995), asynchronous learning networks (Harasim, 1990; Hiltz & Goldman, 2005a), cognitive psychology (Baddeley, 1999; Vygotsky, 1961), the community of inquiry (Garrison, Anderson, & Archer, 2000), social interaction and immediacy in educational contexts (Christophel, 1990; Gunawardena & Zittle, 1997; Kreijns, Kirschner, & Jochems, 2002; Wiener & Mehrabian, 1968), multi-media use (Mayer, 2001), and cognitive load theory (Mayer & Moreno, 2003).

Table 1: Design clusters and principles

Clusters	Principles
Interaction among students	1. Collaborative learning through asynchronous discussion
Structure	2. Social interaction
	3. Tight schedule
Instructor's role	4. Balanced workload
	5. Clearly defined goals and expectations
	6. Time, reaction time and attendance
	7. Moderation
	8. Feedback.
	9. Support and advice
	10. Flexibility and content adjustments
	11. Control and activation
	12. Synchronous office hours
	13. Social presence
Course materials	14. Training
	15. Rich learning environment

The literature review regarding design principle 1: 'Collaborative learning through asynchronous discussion' is included in the remainder of this paragraph. The review of the other 14 principles can be found in the original publication (Smits, 2012).

### ***Collaborative learning through asynchronous discussion***

Definitions of collaborative learning in the literature share important features, but differ in detail. Based on the definitions of several authors (Cohen, 1994; Dillenbourg, 1999; Gokhale, 1995; Lockhorst, 2004) the following definition is used in this study: *Collaborative learning is learning that occurs when students work in small groups on complex learning tasks that are constructed in such a way that students need each other's unique contribution in order to reach a solution.* In the context of this definition, collaborative learning does not refer to the division of labor among students. Collaborative learning refers to students working together on a complex problem whilst constructing knowledge together that exceeds the sum of the parts.

Collaborative learning through asynchronous discussions belongs to the research field of Asynchronous Learning Networks which is related to the field of Computer Supported Collaborative Learning (CSCL). On the basis of Hiltz and Goldman (2005b, p. 5-6) asynchronous discussion is defined as follows: *"An asynchronous discussion is an online discussion in which the participants contribute asynchronously in time. Participants work from the location of their choice and do not need to be online simultaneously. They contribute to the discussion within a restricted time span. Their contributions are written and delivered in an online discussion board on a web platform. The entries remain visible to others during the course of the discussion"*. Asynchronous discussion can be a form of collaborative learning in itself, and is also a means of communication in other types of collaborative tasks, such as group projects and peer feedback.

The main advantage of collaborative learning over individual learning is that it leads to longer retention of learning and to increased depth in critical thinking (Gokhale, 1995). Asynchronous discussion can positively contribute to learning because it enables dialogue and online

collaboration. In an asynchronous discussion exploration, negotiation of meaning and reflection take place, with collaborative knowledge construction as a result. Students have an active role in the learning process, they learn not only from the teacher but also from each other (Coppola, Hiltz, & Rotter, 2002; Harasim, 1990; Jonassen, Davidson, Collins, Campbell, & Haag, 1995). This method is ideally suited for adult professionals who work with each other to design solutions for complex practical problems (Brower, 2003).

From a theoretical point of view the asynchronicity and the written nature of the communication are advantageous for learning. The asynchronicity allows students more time to think about their contributions than is possible during regular discussions (Hiltz & Goldman, 2005b; Meyer, 2003). Participants can reconsider and revise their contributions which positively affects the quality of their contributions. More time to think may also be beneficial to introverted students who tend to contribute infrequently in the rapid stream of communications in the face-to-face classroom (Harasim, 1990; Oblinger & Maruyama, 1996; Pallof & Pratt, 1999). A special feature of asynchronous discussions is that the entries remain visible and can be returned to at a later stage. Online discussion boards enable participants to search and organize discussions (Polin, 2004). Asynchronous discussions consist of written language. Written language has the advantage that it needs a more conscious production than spoken language (Vygotsky, 1961). Writing activities therefore lead to greater depth in the learning process (Langer & Applebee, 1987). The use of written language seems to be an advantage for higher-order thinking processes (Garrison, Anderson, & Archer, 2000).

Several researchers investigated the differences between online and face-to-face (f-2-f) discussions. Jonassen and Kwon (2001) compared the communication patterns in the two types of discussion. Asynchronous discussions seemed to have advantages over f-2-f discussions for solving ill-structured problems, because the messages were more task-oriented and reflective. Moreover, the sequence of the asynchronous messages aligned well with the process of problem solving: problem definition, orientation and development of a solution. Heckman and Annabi (2005) also compared online discussions to f-2-f discussions. On the basis of content analyses they concluded that the online discussions contained more interaction among students and more higher-order cognitive activity. The f-2-f discussions in this study predominantly contained lower-order cognitive activity, and almost all student contributions to the f-2-f discussions consisted of answers to a question from the teacher. There was virtually no interaction among students. The meta review of Bernard et al (2004) is in line with these findings. On average the results of distance learning via asynchronous communication were slightly better than the results of f-2-f education, however a large variance was shown. Analyses that only concerned the written material of asynchronous discussions confirm that these discussions revealed higher-order thinking processes (Aviv, Erlich, Ravid & Geva, 2003; Gunawardena, Lowe, & Anderson, 1997; Meyer, 2003; Schellens & Valcke, 2005).

For several reasons studying through asynchronous discussions is found to be attractive for students. Students with a busy work and personal life do not need to attend to lessons at fixed times and places. They can decide for themselves when to contribute to the discussions (Hiltz & Goldman, 2005b). In addition, asynchronous discussions have proven attractive to students because of the positive learning effects that they experience (Jonassen & Kwon, 2001; Marks, Sibley, & Arbaugh, 2005; Rovai, 2002b). Swan (2001) concludes that the student satisfaction increases when more asynchronous interaction takes place. It is also an advantage that this type of interaction can reduce the isolation that online learners can experience (Arbaugh & Benbunan-Fich, 2006; Moore, 1993). This could protect students against drop out.

Online collaborative learning is not without its problems. The learning outcomes are not always positive (Lou, Abrami, & D'Appolonia, 2001) and the interaction does not always lead to higher order thinking processes (Oliver & Omari, 2001). Some online students do not feel comfortable with collaborative learning (Bishop, 2002; Easton, 2003; Hawisher & Pemberton, 1997; Swan, 2002). Making students participate in collaborative group projects proves to be more difficult than fostering instructive asynchronous discussions (Haavind, 2006; Swan, 2002). In the study of Swan (2002) asynchronous discussions led to a better learning experience than complex group projects. However, asynchronous written discussions also have disadvantages. In asynchronous discussions non-verbal cues are lacking (Garrison et al, 2000), which may give rise to ambiguities. In addition, the time span between contributing and getting a response requires habituation (Hiltz & Goldman, 2005b). A serious problem that has repeatedly been described in the literature is the problem of non-or under-participation. It has not always proved to be easy to get students to participate in asynchronous discussions with sufficient frequency (Barab, Kling & Gray, 2004; Islas, 2004; Polin, 2004; Voogt, Almekinders, Van den Akker, & Moonen, 2005). Learning effects can hardly be expected when there are not enough contributions. Another problem is that higher-order thinking does not naturally arise in discussions. Teacher interventions are necessary in order to promote higher-order thinking in the discussions (Garrison & Cleveland-Innes, 2005). Collaborative learning, online or otherwise, depends on the quality of several factors that structure interaction (Cohen, 1994; Dillenbourg, 1999). Cohen (1994) mentions the following factors: the nature of the task, the task instruction, preparing students for collaborative learning and the role of the teacher. At the start of an e-learning program many questions arise concerning practical aspects of these factors. Dillenbourg (1999) warns that there are no clear answers to these questions and that complex interactions between the various effects determine the outcome. At the start of the Windesheim master SEN program the main questions were: what is the optimal group size, what types of tasks are appropriate, how can students be prepared for collaborative learning and how does assessment take place, individually or in groups?

The literature is inconclusive about the optimal group size for asynchronous discussions. Aspects that play a role in this discussion are the degree of interactivity and learning, the risk of cognitive overload and the workload of teachers (Burke, 2005). Vrasidas and Mclsaac (1999) found that a group of four students was too small for productive asynchronous discussion. Schellens and Valcke (2006) found groups of 8-10 students to be more task-oriented than larger groups. Moreover, these smaller groups often reached the higher phases of knowledge construction. They argue that cognitive overload occurs when groups are larger than 12 students. However Swan, Shea, Fredericksen, Pickett, Pelz, & Maher. (2000) believe that 11-20 students constitute an optimal class size. For the current design, these findings mean that a group should be sufficiently large (> 4) to generate enough contributions, and small enough (<13) in order to avoid cognitive overload.

In her review Cohen (1994) concludes that poorly structured complex problems with multiple possible outcomes are perfectly suited for collaborative learning because the group members need each other to reach an answer. This means that authentic and complex practical problems are suitable material for collaborative learning (see also Kirschner, Strijbos, Kreijns, & Beers, 2004; Schellens & Valcke, 2005). There is a multitude of methods that may be used to work on these problems. In the context of online learning the most researched teaching method is the asynchronous discussion. The effectiveness of other methods is less established (Jonassen, Lee, Yang, & Laffey, 2005). Examples of other methods include seminars with presentations and discussion, peer feedback, simulations, role-plays and projects in which a product is



created collaboratively. In this type of project students collaborate on a case study, a research tool, or devise examination questions together (Benbunan-Fich & Hiltz, 2003). Other authors mention gaming as a teaching method (Cronje, Adendorff, Meyer, & Van Ryneveld, 2006). In all these methods interaction and negotiation are essential to bring about collaborative learning (see Dillenbourg, 1999). This means that discussion is integral to such methods. For the Windesheim e-learning design it was decided to use asynchronous discussions as the main approach to collaborative learning. To a limited extent other approaches would also be used: collaborative work on a product, peer feedback and role-play.

Asynchronous collaborative learning has advantages as well as disadvantages. The advantages for the learning process led to the inclusion of asynchronous collaboration as an important feature of the master SEN e-learning design. In order to compensate for disadvantages, a number of other design features were introduced.

Design principles of the cluster 'structure' are used to reach acceptable levels of participation. To foster participation in the group discussions it is important to emphasize an obligation to participate as well as individual accountability (Slavin, 1994; Kreijns, Kirschner, & Jochems, 2003). Because of this the master SEN e-learning program was designed in such a way that adequate participation in discussions is required before students get permission to hand their final individual paper. The participation requirements are clarified for students through the use of rubrics based on Pallof and Pratt (2003). Other disadvantages of asynchronous collaborative learning are dealt with through the instructor's role. The literature shows that proper preparation and coaching are necessary when students embark on collaborative learning (Cohen, 1994; Kreijns, 2004). Therefore it is important that instructors clearly communicate and monitor expectations. Higher-order thinking does not always occur spontaneously in asynchronous discussions. In the master SEN program the instructor's role as moderator of discussions is seen as important in order to promote higher-order cognitive processes.

### **Expert consultation**

The third component of the analysis phase was the expert consultation. Three experts in e-learning were consulted in individual sessions. They were selected because of their expertise and research in the field of educational technology in Higher Education. Two experts had been involved in developing an e-learning environment for university teaching. They supported teachers in implementing this environment. One of them also taught online students. The third expert is very experienced in developing, teaching and researching asynchronous online university courses, both nationally and internationally.

The consultation consisted of an interview and a walk through of the first prototype of an e-learning course which was built by the researcher on the basis of the first rough draft of the design. In this rough draft all principles listed in Table 1 were present. The first prototype was well aligned with these principles and completely developed for use with students.

In semi-structured interviews the experts gave their opinion on the proposed design principles. The interviews were recorded, transcribed and summarized. In order to weigh their contributions their differing fields of expertise were taken into account. When the experts contradicted each other than the statements by the most experienced expert on the specific topic were assigned a greater influence.

By and large the responses of the experts confirmed the proposed design clusters, although one of the experts reacted negatively to the asynchronous discussion and to collaborative

learning. His point of view was that asynchronous discussions and collaborative learning create dependency among students which leads to conflicts and delay. Instructors are forced to deal with the problems that arise and they are not well prepared to do this. According to this expert students prefer to work on their own. The two other experts emphasized the fact that asynchronous communication is slow and reflective and leads to active learning, which is valued by students. According to them requiring students to contribute and monitoring participation can prevent problems with collaboration. More experienced students tend to become more and more independent in the asynchronous discussions.

The confirmation from the other two experts (one of whom was very experienced in asynchronous e-learning) was needed to convince the master SEN management of the suitability of the current design. Regarding a number of issues the experts expressed specific advice. They cautioned to be alert to work load and instructor's skills. The online office hours did not generate positive comments. The online office hours were non-mandatory audio conferences using Breeze in fixed time slots. During the office hours students would be given the possibility to communicate with their instructors via the synchronous Breeze platform, so that the instructors could provide support when needed. It was decided that the synchronous office hours would be tried out in the pilot phase. After this try out, the decision would be made whether or not to continue the application of this principle. The interviews also generated some specific guidelines for the formulation of effective and motivating assignments for students.

### **3. The pilot phase and the implementation phase: Usability of the design**

In the pilot phase the central research question concerned the usability of the design. In this phase of the study usability was defined as practicality and attractiveness for students. In paragraph 3.1 the results of the pilot phase are discussed for all four design clusters. In the implementation phase the two research questions concerned usability and effectiveness of the design. In this phase usability was defined as practicality and meaningfulness for students and instructors. Effectiveness was defined in terms of dropout, academic success and student satisfaction. The results on usability in the implementation phase can be found in paragraph 3.2. The results on effectiveness are discussed in paragraph 4.

#### **The pilot phase**

In the pilot phase two e-learning courses were fully developed according to the design principles and the constraints that were identified in the analysis phase. The courses were built in Blackboard (version 7). The two courses were tested in the pilot phase with three students. Two of these students lived in the Netherlands, one student had the Dutch nationality but studied from Asia where she worked in an international school. All three students were female. Two were experienced teachers in primary education, the third had recently finished her bachelor in primary education. Each course had a duration of eight weeks, and the two courses were conducted consecutively. The researcher participated as e-learning instructor. Usability was examined through quantitative and qualitative analysis of digital student messages and through semi-structured interviews with all three participating students. For the qualitative analysis of the student messages a coding scheme was developed on the basis of the scheme developed by Garrison, Cleveland-Innes, Koole and Kappelman (2006). Inter-scorer reliability was measured by the researchers and proved satisfactory.

The results of the pilot phase are described in the following sections for each of the design clusters.

### ***Interaction***

In this cluster the two design principles were:

1. Collaborative learning through asynchronous discussion
2. Social interaction

From the pilot phase it was concluded that asynchronous collaborative learning (design principle 1) within a tight schedule was feasible with a small number of students. The students responded enthusiastically to the asynchronous discussions. They experienced the discussions as highly instructive. Comparison to other types of collaborative activities showed that the discussions were easier to organize, led to more equal participation and were regarded as the most instructive. These results confirmed the findings of Haavind (2006) and Swan (2002) that it is harder for online students to work on group projects than on asynchronous discussions, and that asynchronous discussions led to better learning results than complex group projects.

Learning to participate in online asynchronous discussions proved more difficult for students than expected. Initially students were inclined to deliver comprehensive individual assignments instead of contributions to a discussion.

Neither the literature nor the experts yielded clear guidelines regarding the optimal group size for e-learning. Working in small groups (2-3) persons proved successful in the pilot courses. In the interviews the students expressed a preference for small groups of 2-3 persons. One of the participants was an experienced e-learner in other Dutch and English e-learning initiatives. She made a comparison between large and small groups that she had experienced. She clearly preferred the small group for the interaction and the learning process.

Regarding the social interaction (principle 2) no conclusions could be drawn from the pilot courses. A number of preconditions for social interaction within this setting could not be fulfilled: the students did not study together during a prolonged period and there was no introductory face-to-face meeting. The amount of social interaction remained low in the pilot phase.

### ***Structure***

In this cluster the three design principles were:

3. Tight schedule
4. Balanced workload
5. Clearly defined goals and expectations

It took some time getting used to, but after some time the students adhered to the prescribed schedule (principle 3). Problems occurred when students had not read all the documents. It was decided to request beginning students in the implementation phase to print the schedule and the list of e-learning tasks and to keep these next to their computer. In the pilot phase it proved to be difficult to realize workload balance (principle 4) and clarity of instructions (principle 5). These problems also existed in the face-to-face courses. The existing problems needed more frequent and thorough attention in the online courses due to the transactional distance between students and lecturers.

### ***Instructor's role*** (principles 6-13)

In this cluster there were eight principles, principles 6-14. However, principle 14 was outside the scope of the pilot phase. The following eight principles were investigated in the pilot phase:

6. Time, reaction time and attendance
7. Moderation
8. Feedback

9. Support and advice
10. Flexibility and content adjustments
11. Control and activation
12. Synchronous office hours
13. Social presence

All but one of the principles of the instructor's role (principles 6-13) were deemed usable and important for the students. The importance of the characteristics 6 (reaction time), 7 (feedback) and 8 (moderation) was mentioned most often in the student interviews. The synchronous office hours (principle 12) raised many technical problems and proved difficult to plan. Even the student who participated in all sessions doubted whether the advantages outweighed the disadvantages. These findings are consistent with the doubts expressed by the experts with respect to the outcome of such office hours and the associated technical problems. It proved difficult to plan the office hours because of time differences (Asia - Europe) and tight schedules. Based on these findings it was decided to drop the synchronous office hours. An additional argument to do so, were the technical difficulties with the sound settings on their local computers that the participants experienced. This seemed too risky with a larger group.

#### **Course materials** (principle 15)

The students actively used the contents of the learning environment. The main components of the learning environment were articles, short written explanations of core topics, video fragments, narrated PowerPoints, interactive questions and written worked examples. Their most positive reactions related to the interactive questions and the video fragments. Some students did not appreciate the narrated PowerPoints. On the basis of these findings it was decided to create more interactive questions for the courses in the implementation phase. Further research was needed into the value of the narrated PowerPoints. Producing narrated PowerPoints is labor intensive. Based on a limited number of students, it was not yet clear whether the efforts in this area could be restricted. It did become clear that it was important to produce PowerPoints with accompanying written text (script) and to make these available for students in addition to the narrated PowerPoints. Not all students listened to the narrated PowerPoints, some students preferred reading the script. This may have been caused by problems with the local sound settings of the students' computers.

#### **The implementation phase**

After the six months of the pilot phase, the courses started in the implementation phase. This phase was two years in duration. In the first year cohort 1 started with 39 e-learning students, and in the second year cohort 2 started out with 38. Cohort 1 was followed during 2 years, cohort 2 was followed during one year, which was the second year of the implementation phase. Study participants in the implementation phase were the 77 students and 15 instructors. Most students (92-95%) were women. The mean age was 40 years ( $SD = 9$ ). All students had a bachelor degree and they worked in education or in private practice. The 15 participating e-learning instructors had no prior experience as e-learning instructor. There was only one man involved and 14 women. They all worked for the Windesheim master SEN and all but one of them were experienced Blackboard users on the basis of their experiences with blended learning. They were to combine their f-2-f teaching tasks with e-learning teaching tasks. They received a one-day training by the researcher before they started their online work. The short duration of the training was caused by the heavy workload of the instructors. They were not able to spend more time taking the course. An instructor's manual was provided and intensive on the job assistance was available.

Usability was examined through quantitative and qualitative analysis of digital student messages, quantitative analysis of instructor's messages, a research log, semi-structured interviews with instructors, document analysis and student surveys. Eight different surveys were used. Four surveys addressed general aspects of e-learning and the other four each targeted one of the four the design clusters. Where possible surveys developed by other researchers were revised and used. Table 2 summarizes the surveys that were used and their origins.

Table 2: Surveys in the study

Translated and adjusted surveys	Original name
TAC (general aspects)	Teacher Attitudes towards Computers (Knezek, Christensen, & Miyashita, 2000; Moonen, 2001)
Interaction among students (design cluster)	Classroom Community Scale (Rovai, 2002)
Survey Windesheim master SEN	Original name
Master SEN evaluation (general aspects)	Master SEN evaluation
Surveys developed for this study	With translated items from:
Feelings about e-learning (general aspects)	-
Autonomous learning (general aspects)	-
Instructor's role (design cluster)	The Online Learning Environment Survey (OLES) (Pearson & Trinidad, 2006) Web-based Course Evaluation (Stewart, Hong, & Strudler, 2004)
Effect of learning materials (design cluster)	e-Learning Experience Questionnaire (Ginns & Ellis, 2007)
E-learning organization (design cluster)	Web-based Course Evaluation (Stewart et al., 2004) e-Learning Experience Questionnaire (Ginns & Ellis, 2007)

The newly constructed surveys were presented to a language teacher and to two researchers for wording and validity assessment. This led to improvements in several items. The reliability of the subscales in the surveys was tested with Cronbach's alpha. All scales proved reliable ( $\alpha \geq 0,70$ ) whereas most scales proved highly reliable ( $\alpha \geq 0,80$ ). Convergent validity was calculated (Pearson's  $r$ ) and proved satisfactory for conceptually related scales.

During the implementation phase all surveys were administered several times. Table 3 displays at which points in time the different instruments were used. We were careful not to overload students with surveys in order to maximize response.

Table 3: Timing of the surveys

Surveys	During Crs1*	After Crs1	After Crs2	After Crs3	After Crs4	During Crs5	After Crs5	After Crs6	After Crs7
TAC	x					x			
Master SEN evaluation		x	x	x	x			x	x
Feelings about e-learning		x			x		x		

Table 3: Timing of the surveys (continued)

Surveys	During Crs1*	After Crs1	After Crs2	After Crs3	After Crs4	During Crs5	After Crs5	After Crs6	After Crs7
Autonomous learning		x	x	x	x				
E-learning organization			x					x	x
Effect of learning materials			x					x	x
Instructor's role		x	x	x	x			x	x
Interaction among students		x	x	x	x			x	x

\* Crs=Course, eight weeks in duration

The results of the analysis of the quantitative and qualitative data from students and instructors are discussed in the next sections for each of the design clusters.

### **Interaction among students**

In this cluster two design principles were described:

- Collaborative learning through asynchronous discussion.
- Social interaction.

Both design principles showed some problems but proved to be usable after several adaptations. The problems that arose and the most important changes that were implemented are shown in Table 4.

Table 4: Interaction among students: Problems and changes

Principle	Main problems encountered	Changes that were made
Collaborative learning through asynchronous discussion	Quantity and reading load	Groups have 5-8 participants. Instructors merge groups when groups become too small. Explicitly defined expectations with respect to minimum and maximum number of words: 100-300 words. The use of attachments is not allowed in discussion contributions.
	Quality of the contributions	Rubrics and criteria for the quality of contributions were added. Instructors provide individual feedback when needed on the quality of contributions based on rubrics and criteria.
	Timing and workload	The number of discussion assignments was reduced to one in 1½ week.

Table 4: Interaction among students: Problems and changes (continued)

Principle	Main problems encountered	Changes that were made
Social interaction	Group composition and connectedness	Students choose their own groups. The importance of social exchange among students is emphasized, instructors participate to model the desired behavior when needed.
	Communication problems	Establishment of netiquette rules. Instructors delete messages that do not conform to netiquette and provide individual feedback to the student(s) involved.

*Collaborative learning through asynchronous discussion*

After these modifications this principle proved to be usable for the Windesheim master SEN. The students contributed to the discussion assignments in a satisfactory way, both qualitatively and quantitatively. The student scores on perceived learning from the discussions were high and the instructors confirmed the learning effect in the interviews.

*Social interaction*

After the modifications both the students and the e-learning instructors valued social interaction among students. The instructors noticed that social interaction between students led to mutual encouragement and support, and to a more enthusiastic interaction in asynchronous discussions about course content. Connectedness and social interaction were sufficiently realized in the second cohort.

**Structure**

In this cluster three design principles were described:

- Tight schedule
- Balanced workload
- Clearly defined goals and expectations.

All three design principles showed some problems but proved to be usable after several adaptations. The problems that arose and the most important changes that were implemented are shown in Table 5.

Table 5: Structure: Problems and changes

Principle	Main problems encountered	Changes that were made
Tight schedule	False expectations: some of the first cohort students expected to be completely free to study when they liked	More information on the tight schedule for new e-learners. Thorough check of expectations in intake for new e-learners. Early access to the first course; for thorough orientation before the start of the study.
Balanced workload	Workload too high	Maximum of one collaboration- or discussion assignment in 1½ week.

Table 5: Structure: Problems and changes (continued)

Principle	Main problems encountered	Changes that were made
	Students temporarily unable to participate in discussions due to personal circumstances	Ad hoc permission for changes in deadlines. Alternative assignments for students that have been unable to participate; in many cases they summarize the discussion that has taken place.
Clearly defined goals and expectations	Ambiguities in assignments	Unclear assignments were changed or omitted. Instructors provide support in the discussion boards, but also by telephone or via Skype.

#### *Tight schedule*

The tight schedule with compulsory assignments and deadlines proved a useful design principle for the master SEN e-learning courses. In most cases the students adhered to the prescribed study rhythm. Most students experienced the tight schedule as supportive for their own planning. Furthermore the tight schedule proved to be an important precondition for collaborative learning.

#### *Balanced workload*

A balanced workload in the e-learning courses proved important but also difficult to realize. Over time no clear improvement was measured in the workload balance, despite attempts that were made to this end. As a result of this a number of e-learners experienced stress and / or comprehension problems.

#### *Clearly defined goals and expectations*

Clearly defined goals and expectations turned out to be very important to students. In general the students confirmed that the information in Blackboard was sufficiently clear. However the clarity of the assignments and the associated requirements often met with discontent. Despite continuous improvements, unclear tasks and requirements remained a problem for some students.

#### **Instructor's role**

In the implementation phase eight principles determined the role of the online instructor.

- Time, reaction time and attendance
- Moderation
- Feedback
- Support and advice
- Flexibility and content adjustments
- Control and activation
- Social presence
- Training.

These principles proved usable, but many revisions were made to the details of the implementation. Table 6 summarizes the most important problems and changes that were made. The online instructors needed time and support to grow in their complex roles.



The small e-learning team helped the instructors to moderate and to write online feedback for students. The e-learning team also supported the instructors when problems arose with students or with technology.

*Table 6: Instructor's role: Problems and changes*

<b>Principle</b>	<b>Main problems encountered</b>	<b>Changes that were made</b>
Time, reaction time and attendance	The workload of instructors was too high. Continuous nature of the teaching task.	Instructor moderates discussion three times a week (instead of 5). Instructors work with a maximum of two groups (maximum 16 students). Instructors explicitly plan their online work in their agenda's.
Moderation	Instructors had little moderating skills.	The e-learning team helped the instructors in the actual moderating task and provided guidelines on the core features of moderation.
Feedback	Feedback proved too time consuming for instructors	The number of feedback moments was reduced. This was clearly communicated to the students.
Support and advice	At the start of cohort 1 the students' need for organizational and technical support was so high, that instructors spent too much time on this aspect at the expense of other aspects.	An FAQ section was created in Blackboard as well as communication guidelines and technical guides.
Flexibility and content adjustments	Some instructors perceived the assignments and the prescribed discussions as static units with no room for adjustments.	The e-learning team helped instructors with concrete examples of the flexibility of assignments and discussions.
Control and activation	Instructors found it difficult to influence students that were not participating adequately.	The e-learning team composed examples of e-mails for students who were not participating adequately.
Social presence	Initially some instructors did not show social behavior online. At the start, some instructors missed the f-2-f contact with students.	The e-learning team gave feedback and examples of online social behavior.
Training	The manual and the workshop did not lead to the expected results.	Support on the job was arranged for the instructors.

*Time, reaction time and attendance*

Timely reactions and regular visible presence of the instructor proved to be of great importance to students.

After major revisions in this area, time use and time allocation reached an acceptable balance for the online instructors whilst maintaining an acceptable presence of the instructors for the students.

#### *Moderation*

Over time the number of organizational questions decreased and the instructors' moderating skills improved. Skillful moderation by instructors proved to be an important factor in student satisfaction about online learning.

#### *Feedback*

Specific and constructive feedback was highly valued by students. The instructor's need for a less time consuming feedback system remained.

#### *Support and advice*

Support on organizational matters proved to be extremely important for students. The changes that were implemented reduced this aspect of the instructor role to manageable proportions.

#### *Flexibility and content adjustments*

Flexibility and adjustment of the content were very important for some students, but not for all of them.

#### *Control and activation*

Students needed control and activation to keep the collaboration going in a satisfactory way. The instructors considered 'control and activation' as less important than the other aspects of their instructor role.

#### *Social presence*

Social presence proved to be a usable principle. The instructors learned how to express themselves online. While they initially reported missing the face-to-face contact with students, they were very pleased with the online contacts later on.

#### *Training*

Training for e-learning teachers appeared to be important, but the forms that were chosen had disappointing results. Support on the job led to better results.

#### ***Design cluster 'course materials'***

One design principle was described for this cluster: the rich learning environment. The rich learning environment of the e-learning courses elicited enthusiastic reactions from the experts, students and online instructors. Nevertheless the rich learning environment developed over some time in a more efficient learning environment. The diversity of the learning objects decreased in the newer courses. After some time course builders primarily built the sorts of learning objects that were considered to be most instructive by the students. This resulted in an emphasis on compact written explanations, literature, video fragments, worked examples, interactive questions and links to other websites. Narrated PowerPoints were no longer produced. The enhanced efficiency of the learning environment reduced cognitive load for students as well as the complexity of building courses for instructors.

#### **4. Effects of the e-learning master SEN**

As the effects of the e-learning courses three variables were measured: student satisfaction, attrition and academic success. Student satisfaction was measured during the implementation phase per course on a scale of 1-10. Attrition and academic success were measured both during and after the implementation phase: after year 1, year 2, year 3 and year 4. Associations with the satisfaction about the four design clusters were computed (Pearson's *r*). Attrition and academic success were assessed through document analyses and a comparison was made to attrition and academic success of the face-to-face master SEN students. For attrition associations with the satisfaction about the four design clusters were computed (point biserial correlations). The results are described below.

##### **Student satisfaction**

In most cases student satisfaction reached the standard that was set by the management team ( $\geq 7$  on a scale of 1-10). However, in a number of cohort 1 courses, student satisfaction varied substantially. Student satisfaction was associated with the appreciation for the structure, the course materials and the instructor's role. In cohort 1 a negative attitude toward computers was associated with lower student satisfaction.

##### **Attrition and academic success**

Attrition and academic success were comparable with the face-to-face cohort. This was consistent with the targets of the management team. Students who were satisfied with the e-learning structure and student interaction dropped out less often. Study-related anxiety in the first course was not favorable; anxious students dropped out often. Computer attitude showed no relation to drop out and failure.

#### **5. Yields of the study**

Design research leads to improvements in teaching practice. Knowledge is produced, as well as products and professional development of those involved. The master SEN e-learning study produced a number of results. First of all, it yielded knowledge of the four design clusters, the 15 design principles (see Table 1) and of the revisions that proved necessary. All 15 design principles were derived from the literature on e-learning. The usability and effectiveness of 14 of these principles were confirmed in this study, which followed two cohorts of e-learning students. However many practical adjustments were made because of usability issues.

The results of the study may give rise to further theorizing about factors that play a role in the satisfaction, retention and academic success of e-learning students. A reappraisal of the role of the design cluster 'structure' seems warranted, both on the basis of the current study and on the basis of the literature that ties structure to the success of online courses (Swan, 2002), and in particular to favorable learning outcomes (Hwang & Wang, 2004). Structure is the only cluster in this study that is systematically associated with both student satisfaction and retention. This cluster may well play an intrinsically motivating role that can be explained from the basic needs pyramid as described by Maslow (1987). A well-organized e-learning course provides safety and thereby satisfies a basic human need. Chaos ensues in the absence of clear expectations and tight schedules with deadlines (Arbaugh, 2008).

The study contributed to the creation of several products for educational practice, this is a typical outcome of design research (Plomp, 2007). Significant outputs of the study were the 11 different courses that featured in the study as well as all consecutively developed courses for the e-learning initiative that is now (April 2013) in its sixth year of implementation. In addition to

the courses an instrument (Feelings about e-learning) was developed that may predict attrition at an early stage of the study. It would be useful to further investigate this with new cohorts of students.

Another result of the study is the professional development of the instructors involved in e-learning. Based on the results of the present study an e-learning course was built to prepare instructors for their online tasks.

For the near future the study yields follow-up questions with respect to the workload of online instructors. It seems important to determine whether certain job aspects may partly be automated and whether students can play a more important role in feedback and moderation without reducing the cognitive output of the discussions (see de Wever, van Winckel, & Valcke, 2008).

Limitations of the study are: the limited number of students and teachers involved, the limited number of iterations, the fact that almost all participants were women, the limited technical possibilities of Blackboard 8 and the limited digital skills of the age group involved. Given these limitations, the outcomes of the master SEN study do certainly not preclude the existence of other types of effective e-learning design. Both current and future technological developments will lead to new educational opportunities, and will raise new design questions.

## **6. Reflections on lessons learned**

### **Design research in the context of higher education**

The present study is an example of a study initiated within an institute of higher education. The interests and limitations of the institute also meant interests and constraints for the research. An advantage of this situation was that the complex educational innovation directly matched the ambitions of the institute so that the research findings could lead to real and lasting innovations.

Disadvantages of the central role of the institute, were time constraints and limited availability of staff. The practical teaching situation within the Windesheim master SEN limited the number of possible iterations and resulted in abrupt transitions between the cycles in the study. It is important that researchers take into account this type of constraints that are imposed by the educational environment.

Design research protects against implementations that are determined by the political, financial and ideological fads. A well conducted analysis phase provides a solid theoretical, empirical and practical basis for design principles (Van den Akker, 1999). From a financial management point of view the current e-learning design was certainly not the most attractive and obvious design. The design was granted a chance because of the thoroughness of the analysis and confirmation of the resulting design principles by experts.

### **Learning to learn online**

Consideration of the revisions that were made to details in the implementation, shows that these changes were often intended to teach students to learn online. The trend was identified that students drop out early, during or just after the first online course. This confirms the findings of Arbaugh (2004). It turned out to be of high importance to prevent, identify and remedy problems in the early stages of the course.

### **Learning to teach online**

The current study confirms the conclusion in the literature that most new e-learning instructors quickly overcome the differences with regular teaching (Berger, 1999; Conrad, 2004; Kanuka, Collett, & Caswell, 2002). After having taught one course, most online master SEN instructors showed improvement in terms of student satisfaction. Only a very limited number of instructors dropped out after their first online course. However, for most instructors, starting to teach via e-learning was not easy. In the beginning their workload was too high because they had to adjust to the process while supporting students who had to adjust to e-learning as well. Their new role was complex. There was a large amount of written communication and in the first course they had to supervise too many groups that worked on too many assignments. At the start of the implementation phase the instructors lacked guidance to balance their complex online tasks. The online course required not only new teaching behavior, but also aspects of regular teaching skills. The latter did not automatically transfer to the online context. The start of online teaching might be facilitated by an emphasis on the similarities between online and regular teaching. Obviously the differences also merit attention. Important differences are the emphasis on asynchronous written communication, the psychological distance between students and instructors, moderation of the discussions and continuity of the workload.

### **Key source**

Smits, A.E.H. (2012). *Ontwerp en implementatie van de masteropleiding special educational needs via e-learning*. Dissertatie. Enschede, the Netherlands: Universiteit Twente.

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## Educational Design Research for Collaborative Learning: Challenges and Opportunities in Oman

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# 39. Educational design research for collaborative learning: Challenges and opportunities in Oman

David Porcaro & Thomas Reeves

## Abstract

*Constructivist teaching methods, such as Computer Supported Collaborative Learning, have been championed by many educators and international organizations as a way to improve education in developing countries and to prepare students for working within knowledge societies. However, few studies have examined how personal, cultural, institutional, and national factors contribute to the acceptance or rejection of these innovative methodologies, especially in instructivist learning cultures. This chapter outlines one education design research study which was conducted as a doctoral dissertation project that examined how to apply collaborative learning methods to an undergraduate course for pre-service teachers in Oman. This study takes a linguistic cognitive anthropology design research approach, focusing on the role of culture in adopting research methods designed in one context and adapted to another. In addition to describing design principles for preparing collaborative learning environments in a setting like Oman, it outlines the challenges and opportunities of conducting long-term international education design research as a graduate student.*

## 1. Introduction and context

Many international organizations and donors have suggested the best way to develop “knowledge societies” and increase development in the “information age” is to move from simple information sharing, which is most common in recent Information and Communications Technology (ICT) innovations as well as education practices throughout the world, to knowledge building (UNESCO, 2005). If social and economic development is to progress in this manner, it must be built on new ways of knowing - ways that no longer stress passive reception of sanctioned information through memorization and recall, but instead on strategies that foster skills in information gathering, evaluating source quality, collaborating, problem-solving, and ultimately knowledge creation (Bereiter, 2002). For this reason, many educators have turned to Computer-Supported Collaborative Learning (CSCL) as a way to bridge the distances amongst learners (physically, temporally and interpersonally) as well as between learners and relevant performance (Collis, 2008) with the goal of fostering collaborative knowledge creation (Scardamalia & Bereiter, 1993). While it is clear that ICT does not always provide a simple solution to education development’s complex problems (Vrasidas, Zembylas, & Glass, 2009) and may further support inherent power-relations, innovations like CSCL provide great opportunities for students to express themselves and become more empowered in creating knowledge.

However, many of the nations that could benefit most as knowledge societies continue to promote education practices that are largely instructivist in nature; that is, they rely on verbal transmission of information through lectures and textbook readings and a heavy emphasis on memorization of discrete facts that can be assessed through high stakes exams. In the Middle East, traditional instructivist methods may even contribute to the gulf between education and the

critical characteristics needed in the labor force, creating challenges as graduates are unable to find work due to lack of relevant and practical skills (World Bank, 2008).

While many policy makers advocate a shift to constructivist-based social learning methods to aid in educational development (cf. UNESCO, 2005), the debate about the relative effectiveness of instructivist versus constructivist learning is still ongoing (see Donn & Manthri, 2010; Tobias & Duffy, 2009). Nonetheless, the actual process of change from instructivist to constructivist methods has been poorly investigated (Catterick, 2007). Specifically, in a traditionally instructivist learning culture, such as Oman, there is little research into how personal and institutional factors affect the adoption of CSCL.

The purpose of this study, conducted by the first author as a doctoral student in the USA and supervised by the second author, was to understand how students, teachers and institutions adapt to collaborative knowledge-building technologies and practices, as well as to understand what design principles could lead to a CSCL environment that is contextually appropriate for an undergraduate course at Sultan Qaboos University (SQU) in Oman. For this multi-semester international design research study, the following questions were addressed:

1. a. What changes (attitudinal, cognitive, epistemological, habitual, etc.) occur in teachers and students when a knowledge-building CSCL environment is introduced in an Omani undergraduate course? b. How do the students and teachers manage those changes?
2. What are the characteristics of a sustainable knowledge-building CSCL environment in an Omani undergraduate instructional design course, which would take into consideration those changes?

These research questions defined the research project as a whole and research sub-questions were selected to guide the process (see Table 1 and 2 below for a listing of those sub-questions). However, the sheer amount of data collected was enormous, as often happens in design research. This chapter addresses one dimension of those research questions, namely the role culture played in the application of collaborative learning techniques to Oman.

### **Why educational design research?**

Educational technology has been noted as “first and foremost a design field”, and as such, “the paramount research goal of education technology should be solving teaching, learning, and performance problems, and deriving design principles that can inform future development and implementation decision” (Reeves, 2006, p. 61). It was this search for design principles based on a deeper understanding of teaching and learning to solve existing problems that guided this study of the introduction of a knowledge-building CSCL environment in Oman.

Thus, selecting an appropriate research method for this goal was important. According to Reeves (2000), there are at least six major types of research goals: theoretical, predictive, interpretivist, postmodern, design/development, and action/evaluation. The developmental goals of design research are especially useful when “existing knowledge falls short, as is often the case with highly innovative curriculum improvement initiatives” (McKenney, Nieveen, & Van den Akker, 2006, p. 74), or when researchers want to create new learning environments, develop contextually-based theories of learning, understand design processes or increase education innovation (DBRC, 2003). While CSCL studies have historically included laboratory, ethnographic or design research methods to reach their goals (Stahl, Koschmann, & Suthers, 2006), the predictive (e.g., laboratory) and descriptive (e.g., ethnographic) methods of research are limited in several important ways.



For example, while experimental (or quasi-experimental) laboratory studies or randomized clinical trials may be considered the “gold standard” of research because of their ability to isolate variables and determine causal relationships (National Research Council, 2002), this focus on only hypothesis testing limits the scientific process to merely summative evaluation (Phillips, 2006) and may hinder innovation by prematurely proclaiming evaluative judgments regarding the efficacy of educational interventions (DBRC, 2003). In addition, these methods often de-contextualize innovations to the point of insufficiency.

Likewise descriptive methods also fail too often in producing positive educational change. Surveys, along with other descriptive research (such as ethnomethodology, phenomenology, ethnography and case studies) can constrain educational change within the observation stage, and may limit the transformative agendas of educational researchers due to fears of the Hawthorne effect on the observed phenomena (Barab & Squire, 2004).

Design research, however, has as a goal the application of both prediction and description in an attempt to create sustainable educational change while seeking to understand learning *in situ*. Educational design research describes learning situations using a variety of methods, fosters the creation of innovative learning environments, *and* evaluates them through predictive testing methods over several iterations (Stahl et al., 2006). Thus it is best situated to produce practical and socially-responsible research (Reeves, Herrington, & Oliver, 2005).

Furthermore, design research addresses many of the shortcomings of theoretical and postmodern research in that it creates solutions as a goal, rather than assuming that others will convert theory and critique into change. Design research also transcends the goals of formative (or action) research in that it constantly connects design with existing theory and generates new contextually-grounded theoretical knowledge (Barab & Squire, 2004), rather than merely evaluating the effectiveness of a learning practice or design. In this way, design research occupies Pasteur’s quadrant in Stokes’ (1997) matrix, assuming the dual goals of consideration of use and fundamental understanding (Reeves, 2000). The interwoven goals of design research best allowed this research project to address understanding the nature of collaborative knowledge building as well as working with local Omani educators to create solutions that will improve education in their country and lead to greater social and economic development. In the case of this study, we sought greater understanding of the theoretical nature of learning, culture, and change (research question 1a and b), while simultaneously pursuing a design goal of building a learning environment (research question 2).

This study was guided by the beliefs and methods of what Bell (2004) calls “linguistic or cognitive anthropology design-based research,” which places significant emphasis on the localized nature of the practices and norms of the social groups investigated (Omani students) as they actually occur in their specific settings. Bell claims that such a focus allows for detailed study of how new designs are appropriated, resisted, or even repurposed by groups that are assumed to already have significant cultural momentum before any intervention begins. Analysis often documents unanticipated consequences or emergent practices that derive from the cultural worlds of participants never anticipated by the educational designers.

## **2. Preliminary investigation**

This research design began with an informed exploration, or what van den Akker (1999) calls “preliminary investigating,” which involves reviewing the literature, developing theory, and understanding the users’ needs (see Figure 1). This stage included extensively reviewing the

literature of CSCL theory and practice as well as the use of collaborative learning in Arab culture in general and Omani culture specifically. Trends in the literature were analyzed to create a framework for describing the varying elements that shape the interaction between constructivist and instructivist learning cultures.

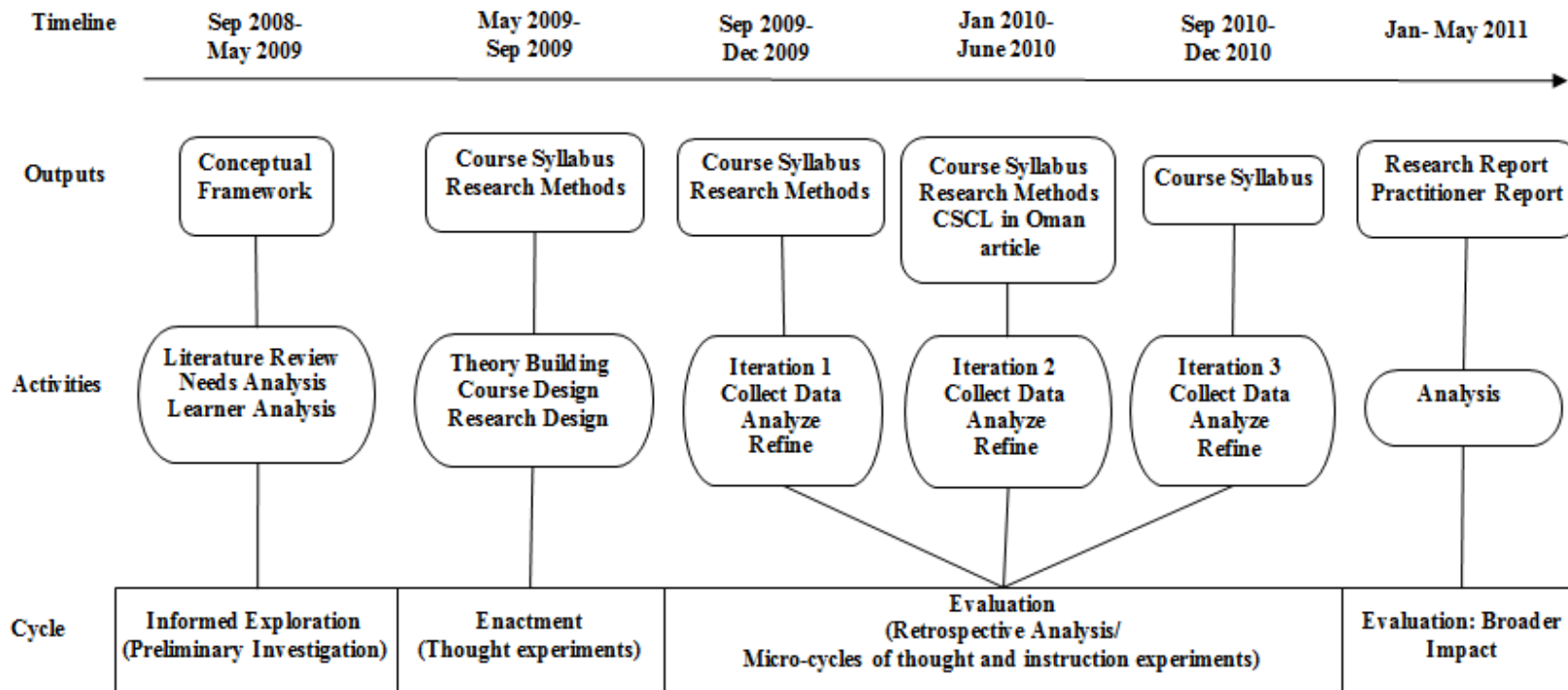


Figure 1: Research design, based on Bannan-Ritland's ILD (2003)

This preliminary investigation led to the creation of a conceptual framework (see Figure 2), that incorporated theories of knowledge-building communities, understanding of the Omani context, and “thought experiments” (Gravemeijer & Cobb, 2006). This conceptual framework was documented as a publishable manuscript (Porcaro, 2011), which more fully describes and analyzes the interacting pieces. However, it is worth summarizing here the key features.

An educational innovation sits at the nexus of teacher, student, and institutional system, all housed within a national context. The national context includes variables that affect how that innovation might be assimilated within the context. For instance, economic conditions, educational tradition, sociopolitical conditions, work force requirements, and location of schools will largely shape how well an innovation is supported or received. The institution also brings to bear resources, policy, and institutional culture that shape the success of the innovation. The teachers and students bring to the interaction their own educational philosophies, which include their epistemology, culture, individual difference, knowledge and skills, and academic habits. All of these elements collide at the point of innovation and result in either congruence between the elements (e.g., a teacher’s constructivist epistemology aligns with the institutional culture of progress and innovation at the school) or conflict (e.g., a student’s individual differences do not align with the academic habits of the teacher). Students, teachers, and institutions may respond to this conflict by dismissing it or adapting to it, while congruence may be ignored or celebrated. This reaction then feeds back to the educational philosophy of the students and teachers, either strengthening them or altering them.

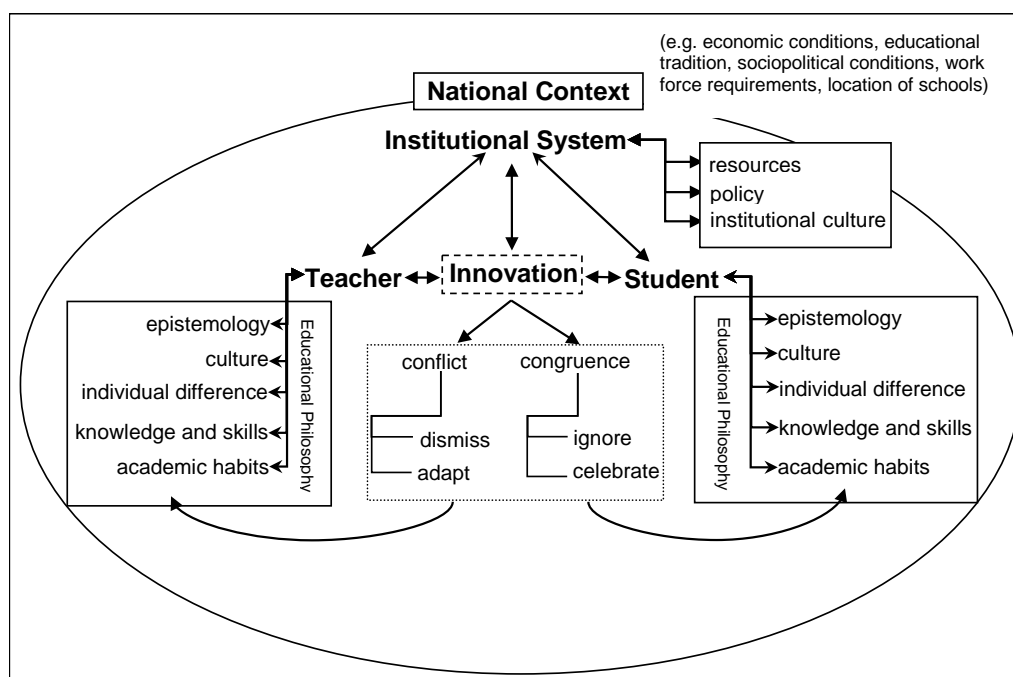


Figure 2: Framework for introducing innovative pedagogies

For this study, the most difficult aspect of undertaking international design-based research as a graduate student was the limited ability to travel to the country during the preliminary phase to undertake needs assessments and collaboratively design the intervention with local practitioners. However, to overcome that distance during this phase, it was necessary to engage a key informant, Mohamed Eltahir Osman, with whom we could communicate, discuss practical

details, and co-design the study. This key informant was the essential local practitioner who helped ensure the project was designed collaboratively. Many phone calls and emails were exchanged to answer questions about the learning context, align our joint expectations, and clarify the needs of the project. That being said, as noted above the bulk of the preliminary analysis of the project was done via literature review from the United States, as well as building from the researchers' personal experiences from having lived or traveled in other Middle Eastern contexts.

From here, we could use the designed conceptual framework to determine which points of my design were flexible and could be altered, and which characteristics the learners should be expected to change. For example, from the literature review, it was discovered that when applying CSCL projects to non-Western settings, a variety of institutional and individual reactions must be considered (Arnseth & Ludvigsen, 2006). Other researchers documented teachers struggling to cede control of their classrooms to their students, as well as students lacking self-directedness and appearing to be motivated only to "make the grade" (Hung, Bailey, & Johnson, 2003). We grouped this factor with others related to epistemology of teachers, which may stand in conflict or congruence to the epistemology of students.

As we reviewed the literature, we noted the possible reactions to differences in students' and teachers' educational philosophies and how they fit within an institutional structure and national context. From there, we could determine what factors we should attempt to control within the intervention design (for instance accounting for individual differences in the way we designed collaborative assignments).

As noted above, we continued reviewing how CSCL projects had been initiated in Oman and the Middle East, and documented this literature review as a publishable manuscript (Porcaro, 2011). As noted above, being distanced from the setting we were reliant on the published literature, as well as informal communications with the key informant in Oman to understand what the state-of-the-art for collaborative learning in Oman was. While studies of CSCL applications are common in Western countries, documented cases are rarer in developing countries, especially the Arab Middle East. We did find, however, several reports focused mostly on cooperative work or computer-mediated communication, leading us to see the necessity of a study of this type considering the dearth of research on the subject.

After reviewing the current cultural and educational setting of Oman, we then verified our understanding of the current context and needs with our key informant via telephone. We sent copies of the conceptual framework for him to review to ensure they were culturally sensitive and reflected reality.

### **3. Design, development, and iterations**

Based on the conceptual framework (see Figure 2), we created an initial design for a collaborative knowledge-building course (prototype 1) for undergraduates at Sultan Qaboos University in Oman (with different students each semester). Through collaboration with Omani educators, we felt that introducing such a CSCL environment would help to move the students to gaining collaborative problem-solving skills that they would need after graduation and allow them to move their learning from passive knowledge acquisition to knowledge building. The first author was fortunate enough to receive funding from a Fulbright Fellowship that allowed him to spend 10 months in Oman to implement and gather data.

Once the work began in Oman, however, some of the key factors of our preliminary design had to be changed. The course around which we had designed the intervention proved to be less appropriate for practical considerations, and another course was chosen - a technology integration course for pre-service teachers. This course not only allowed for greater project-based learning, but was dedicated to pre-service English teachers, whose competence in English (the medium of instruction for courses at SQU) allowed them to engage in computer-supported collaborative learning with greater fluency. Further assumptions about learning in Oman were challenged once we realized that expectations were far from reality (e.g., the amount of work students were expected to do outside of class, the nature of in-class collaboration, and students' technology proficiency). Thus once in country, a month was needed to make design alterations before the course began was essential to successful implementation. These included redesigning the course structure to meet the new subject, reworking how students would be expected to collaborate, and modifying expectations for in-class and out-of-class work. These changes did not, however, erode the initial conceptual framework, but rather supported our initial impression that for successful implementation of innovation, some changes were needed by the teacher as well as the innovation.

During this time the first author worked more closely with a second local key informant, Ali Al-Musawi, who became a cultural translator as well as the lens through which we viewed the design. As a Western-educated Omani, he was able to collaborate closely with the first author to ensure the design was sustainable and more appropriate for Omani students. Many hours were spent discussing things like the oral nature of Oman's culture and how that affected course reading assignments and writing tasks, or what sorts of collaborative interactions between male and female students were appropriate. We were able to plan for the first author to teach during the Fall 2009 and Spring 2010 semesters, and build for sustainability by handing the course over to the Ali in Fall 2010.

### **Course structure**

In this course we introduced exercises based on Brown and Campione's (1996) Fostering a Community of Learners (FCL) model, which we felt would best introduce Omani students to opportunities for collaborative exchange and connections to real-world learning. During these exercises students designed posters, videos, websites, presentations, and other instructional media. They selected their own groups for each assignment and worked individually or in small single-gender groups (3-5). The media they constructed were to supplement the national curriculum for English language in Omani public schools, and had to reflect the realities of technology in Omani classrooms.

The students chose roles and were divided into "jigsaw groups" - an essential element of the FCL model - to learn about various aspects of educational technology. The roles were based on different elements of a multimedia team, namely project manager, web specialist, graphic designer, instructional designer, and audio/video specialist. Each student was responsible to independently learn more about some aspect of their role and collaborate online with others who shared their roles. They then rejoined their project groups and provided some level of expertise in their role to the project. During one class session, the students rotated around the room in either all-male or all-female "cross-talk" groups to allow them to share their knowledge and experiences with students from other groups. Taking on specific roles and creating authentic artifacts not only allowed the students to learn the skills of the English as a Foreign Language community of practice (Lave & Wenger, 1991), but immersed them in a form of cognitive apprenticeship (Collins, Brown, & Newman, 1987).

During these tasks, students formed knowledge-building communities of their own using Moodle (including discussion forums) and Wikis, as well as Future Learning Environments 4 (FLE4), an open source plugin for WordPress blogs (see Muukkonen, Hakkarainen, & Lakkala, 1999). FLE4 provided scripts for online collaboration in an attempt to guide their discussions and artifact creation toward knowledge building, helping the students to “rise-above” other students’ comments as they built theory, questioned other students’ assumptions, and linked ideas to relevant literature. Students’ collaborative work was conducted online, so that mixed-gender groups could share ideas. Collaboration was conducted both synchronously (during class time) and asynchronously, face-to-face (in single gender groups) and online.

### **Research methods**

Over the course of these three interventions, and concurrent with implementation, a variety of mixed methods (DBRC, 2003) were used to collect formative data about the course (van den Akker, 1999). This allowed us to answer practical as well as theoretical questions on the intervention. In order to control the extensive and sometimes overwhelming (Brown, 1992; Dede, 2004) data collection, we tried to focus collection efforts on information richness and process efficiency (van den Akker, 1999). The theoretical framework developed during preliminary investigation became a useful tool for selecting appropriate methods, as well as a filter through which to analyze collected data (see Table 1).

For the first research question, we sought to understand the ways institutional structures and students’ educational philosophies affected the introduction of innovative curricula, such as CSCL. To do this, we asked students to complete pre-, mid- and post-term questionnaires to assess their educational philosophy and attitudes toward collaborative knowledge building. The questions concerning epistemology were based on an English and Arab language questionnaire developed by Karabenick and Moosa (2005) for use by Omani university students.

In order to understand more deeply the reaction of students to the innovative pedagogy (Brown, 1992), the first author selected, based on their initial reactions to the course and variety in beliefs, three students during the first iteration as cases for further study. The three students were purposefully selected to provide maximum variation in their reaction to constructivist education, ranging from congruence to conflict. Each of the students was in their 4<sup>th</sup> or 5<sup>th</sup> year of the English language teaching program at SQU and came from different regions of Oman.

Table 1: Methods matrix for research question 1

<b>Research Methods Matrix</b>									
What changes (attitudinal, cognitive, epistemological, habitual, etc.) occur in teachers and students when a knowledge building CSCL environment is introduced in an Omani undergraduate course? How do the students and teachers manage those changes?									
	<b>Research Methods Sub-questions</b>	Observations/Course debriefs	Case student interviews (3)	Student focus group	Student questionnaire (pre, mid, post)	On-Line Data	Assignments	Teacher/staff interviews	Available documents
Institutional System	a. How do available resources affect adoption?	✓						✓	✓
	b. How does current policy affect adoption?	✓						✓	✓
	c. How does institutional culture affect adoption?	✓						✓	
Student Educational Philosophy	a. How does student epistemology affect adoption?		✓	✓	✓				
	b. How does a student's culture affect adoption?	✓	✓	✓	✓				
	c. How do students' individual differences affect adoption?	✓	✓	✓	✓	✓			
	d. How do students' knowledge and skills affect adoption?		✓	✓	✓		✓		
	e. How do students' academic habits and expectations affect adoption?	✓	✓	✓	✓	✓	✓		

These case students each participated in three one-hour semi-structured interviews - at the beginning of the course, mid-term and at the end of the course. Following Seidman's (2006) recommendations for conducting three-session phenomenological interviews, the first interview focused on the students' history and context, the second focused on their experiences in



learning an innovative curriculum, and the third focused on the meaning the student made of the experience.

During the second iteration, we sought greater breadth in understanding the student experience. Therefore, instead of selecting case students, we chose to employ student focus groups at the end of the semester. The first author conducted one male focus group (n=3 students) and one female focus group (n=4 students). The questions for this interview focused on the students' reactions to the course and their experiences with collaboration.

Since during the first two iterations the first author was both the teacher and researcher, he also played the role of participant observer. His observations of the collaborative sessions were discussed with other educators at SQU and he kept a regular blog of observations.

Furthermore, since many of the students' collaborations and discussions were online, the discussions on Moodle, course Wikis and FLE4 were recorded online, as well as copies of artifacts from the courses were recorded.

In order to answer the second research question, we sought to assess the legitimacy, efficacy, and viability (McKenney et al., 2006) of the learning environment through formative evaluation methods (see Table 2). As part of classroom observations, the first author monitored the students' use of the learning environment. The post-term survey also included questions about students' experiences with the environment and any refinements they might suggest.

Table 2: Methods matrix for research question 2

<b>Evaluation matrix</b>									
Research Question Two: What are the characteristics of a sustainable knowledge-building CSCL environment in an Omani undergraduate instructional design course?									
	<b>Evaluation sub-questions</b>	Observations/course debriefs	Expert review	Case student interviews (3)	Student questionnaire (pre, mid, post)	On-line data	Assignments	Student focus groups	Teacher/staff interviews
Legitimacy	a. Is the course design harmonious, consistent and coherent?		✓	✓	✓				✓
	b. Does the course reflect current scientific insights or best practice?		✓						✓
Efficacy	a. Did the course help students build knowledge collaboratively?	✓		✓	✓	✓	✓	✓	
	b. What knowledge was learned by students?	✓		✓		✓	✓	✓	
	c. What skills were developed by students?	✓		✓	✓		✓	✓	
	d. How did the course appeal to students?	✓		✓	✓			✓	
Viability	a. Is the course practical for SQU?	✓			✓				✓
	b. Is the course relevant to the needs of SQU students?		✓	✓	✓			✓	✓
	c. Is the course sustainable and/ or scalable within Omani higher education?		✓		✓				✓

Case student and focus group interviews also included questions evaluating the students' experience with the course and course tools. In addition, at our request, seven external

reviewers from various countries, chosen for their understanding of Omani higher education, collaborative knowledge building, or teacher training, reviewed the course.

Through micro-cycles of “thought experiments” and “instruction experiments,” the learning environment was developed and a local instructional theory emerged (Gravemeijer & Cobb, 2006). At the end of each prototype, we reviewed the results of the implementation through what Edelson (2002) calls “retrospective analysis,” and refined the design in preparation for a second, and a third implementation (see Figure 3). We compared issues of feasibility and project implementation to examine what areas of conflict or congruence existed, based on the conceptual framework. From there, we noted areas that we felt needed to be changed in the course design (Innovation), the teacher, or the student.

For example, from interviews and questionnaires it was discovered that students had a limited capacity to write individual reports on their assigned roles, due to the oral nature of Omani culture. Here the students’ culture did not align with the teacher’s, so changes were needed in the course innovation. Thus we decided that a group wiki would allow students to share the burden of writing while still producing a substantial course artifact. However, the results of the second semester observations, artifact review, and focus groups with students demonstrated that this still exceeded the academic habits and expectations of students, who felt the workload was excessive. Thus there was conflict with the teacher’s academic expectations, so changes were needed in both the innovation and the teacher’s educational philosophy. At the end of each cycle, the preliminary findings were presented at regional education conferences to further discuss the results with peers in the Middle East to gain additional insight and feedback.

Semester 1 (n=27) Design	Semester 2 (n=21) Refine	Semester 3 (n=33) Transfer
<ul style="list-style-type: none"> <li>• Jigsaw groups for media roles</li> <li>• Students prepare report on new knowledge gained about role</li> <li>• Consequential task: build multimedia kit in groups of 4-5, using new knowledge from role</li> <li>• Content: Unit of instruction from Omani national curriculum for English language</li> <li>• Used wiki and FLE4-enabled blogs for jigsaw group and multimedia design group discussions</li> <li>• One day in the semester devoted to cross-talk, between group discussion (all male, and all female)</li> </ul>	<ul style="list-style-type: none"> <li>• Students expressed technical and user difficulty with wiki: moved to Moodle platform</li> <li>• Limited capacity in individual report writing and information literacy: moved to group Wiki writing.</li> <li>• Limited use of online tools for group discussion: tools were available but optional for group discussions, face-to-face and other methods (e.g. SMS) were encouraged.</li> <li>• Limited understanding of knowledge building, and use of tools: greater teacher support, one-on-one consultation with students.</li> </ul>	<ul style="list-style-type: none"> <li>• Limited teacher preparation and tool maintenance time: removal of wiki and FLE4-enabled blogs, Moodle discussion only.</li> <li>• Excessive workload for students: course requirements for consequential task simplified.</li> <li>• Change in teaching style: flexibility in implementation of FCL, student roles and consequential task.</li> <li>• Limited familiarity with knowledge-building concepts: More instruction on collaborative and student-centered methods at beginning of course, and weaved throughout the course.</li> </ul>

Figure 3: Major changes made between iterations

In order to improve validity and reliability, or what Lincoln and Guba (1985) call trustworthiness and credibility, we attempted to triangulate the most theoretically important data (Stake, 2000) through multiple data types and sources (DBRC, 2003), as well as by working collaboratively with Omanis and other experts in joint evaluation (Van den Akker, 1999) and member checking of findings (McKenney et al., 2006). We also attempted in the description of the case to be

“thick” enough to allow the reader to determine the generalizability of the study and usefulness of the findings (Stake, 2000).

The evaluation criteria were analyzed after the final (third) implementation, and a research report was generated focusing on what Bannan-Ritland (2003) calls broader impact, in an attempt to generalize the results to other contexts. This is available in two versions, a technical report (Porcaro, 2012), and a practitioner’s guide (Porcaro & Al-Musawi, 2011) which broadly details the lessons learned from the study. The second of these was co-authored by Ali Al-Musawi, a key Omani collaborator. We felt this co-authorship was essential to the long-term sustainability of the ideas and the validity of the findings.

#### **4. Project results**

In undertaking this research study, we hoped to discover design principles for both process and product. The former were focused on the theoretical implications of the intervention, such as the role of culture and educational philosophy in educational change, and what elements of CSCL and knowledge building were well aligned to this setting. The results of these efforts are outlined in more detail elsewhere (Porcaro, 2013; Porcaro & Al Musawi, 2012).

In terms of process, this study developed a greater theoretical understanding of the role of culture in collaborative learning. Because of the extensive time needed to undertake this inductive analysis, and due to the limited time during project implementation (since the first author was also designing and implementing the course at the time), analysis between iterations focused solely on formative design modifications, and less on deepening theory. Understanding of the role different conceptual framework concepts, such as culture, played in the design application were examined *ex post facto*, and thus design modifications based on theme were limited. This points to the need for further modifications and testing of the design in the future.

While there was not enough time in the dissertation study to analyze deeply all of the framework’s variables, one topic (culture) was selected for focused attention. Other variables were left open for potential future analysis and reporting. We began the case-study analysis by coding the interviews and artifacts according to the categories of the conceptual framework, then analyzed the data inductively across the case to further define and describe the key themes. This led to the creation of subthemes, and all project data was coded by those sub themes. Data from the case, such as artifacts and interviews, were used to bring meaning to the sub-themes.

While modifications occurred between iterations, it was not until the project’s completion that we began to see more clearly the role of culture in these changes. Culture affected the students, the teacher, and the design in several ways. For instance, we noticed during the first iteration that students were unwilling to engage in text-based assignments, or spend much time reading. We began to shape a theory around the idea of oral learning, but it wasn’t until the deeper analysis of the whole case after implementation that our understanding began to take shape, and we could see that the reliance of students on oral over textual learning meant that students were less likely to adapt to written assignments and text-based collaboration. (A detailed description of these findings can be found in Porcaro, 2013). We realized that this was something the teacher needed to recognize and adjust expectations accordingly. This idea, along with other examples of culture’s role in the design, were organized into design principles for each sub-theme (see Figure 4).

To further outline the product-related design principles, we focused on the practical considerations of the intervention and sought to explain to practitioners the implications of designing and implementing a similar course in the Middle East or similar learning context. The second set of design principles developed focused on the study as a whole and described considerations practitioners should keep in mind when designing, implementing, and providing technical support to a CSCL project in a similar setting (see Figure 5).

Further testing and refining of the course and design themes are necessary, but can be used to enhance understanding of the changes that occur in teachers and students when introducing knowledge-building CSCL environments in Oman and the way students and teachers manage those changes, as well as some of the key design principles necessary for a sustainable CSCL course in Oman.

#### Oral Learning

- Online discussion may not be preferred due to large amounts of writing and reading. Where possible, allow face-to-face collaboration options.
- Students are often not skilled in writing traditional research projects. Use alternative ways for students to report, especially orally, such as presentations, etc., or provide strong scaffolding.

#### Physical Setting

- While male and female entrances may determine where students are comfortable sitting, where possible arrange seating in small groups, rather than in rows. In order to make the students feel comfortable, this may mean dividing the class into two halves.

#### Teacher as Authority

- Provide opportunities for the students to take initiative and control their learning. This may include the teacher helping the students choose topics for jigsaw specialization, or allowing students to choose between a selection of project options. Students may not be used to this, so the teacher must provide extra support and scaffolding.
- Where possible, let students teach each other, and the class, formally or informally. Teachers may feel it difficult to learn from their students, so moving from a teacher-centered classroom to a student-centered classroom may take time.

#### Gender

- Male and female face-to-face interactions will make many students uncomfortable. Where possible, provide opportunities for students to discuss online, or share their ideas with the whole class.
- Realize that many females may feel uncomfortable presenting in front of male students. Build their confidence by allowing them to present either in small groups with other female students first, or online.
- Since many students feel comfortable with the anonymity of online discussion, allow students to post things anonymously or using pseudonyms of their choosing.

#### Acceptance of Technology

- While many students may welcome technology, others may need the teacher to demonstrate how technology supports local values
- Be aware that many students come with very limited technological exposure. So allow alternative assignments based on different levels of technology, or allow them to work with other students.

#### Religion

- When designing the course, be sensitive to the values of Islam. While varying interpretations of Islam exist, if the teacher shows respect for religion, the students will be comfortable with any differences between them and the teacher.

#### Collaboration in Society

- Arab society is built on collaboration and helping others. Where possible build upon students' experiences in collaboration within the course activities.
- While students may not be comfortable disagreeing with teachers or other students, they often have real-world experience arguing points and negotiating solutions. Build students' collaboration skills from this base.
- Some students may work only with students from similar tribes or regions. Allow students to form their own groups, but provide opportunities for students to work with others in the class.

Figure 4: Design principles around theory for the concept culture

## Design Considerations

- Build on the theoretical foundation of FCL: activity, reflection, collaboration, and community.
- Apply to practical courses or subjects; coordinate with practicum or internship courses as much as possible
- Utilize with senior students, or students proficient enough in the language of instruction to argue their position through online discussion
- Explain purposes and processes of collaboration thoroughly before beginning projects
- Allow ample early practice with CSCL tools before undertaking consequential task
- Provide in-class time to collaborate and limit out-of-class expectations for meeting and collaborating
- Place emphasis on performance or production assessment rather than traditional assessment
- Provide ample opportunities for students to share ideas in class as well as across genders online (cross-talks, jigsaw groups)
- Form groups early and provide preliminary small-scale projects to facilitate relationship building

## Teacher Considerations

- Be committed to collaborative knowledge-building principles
- Create peer-based relationships with students
- Motivate and provide enthusiasm for students
- Help students feel comfortable to express themselves freely
- Monitor group work in class; frequently cycle through groups and discuss group progress
- Provide students with individual advisement on their project roles
- Give feedback and support in online discussions

## Technical Considerations

- Provide online space for mixed-gender idea sharing
  - Allow students to maintain anonymity or choose a pseudonym
  - Provide spaces for groups to discuss their work privately
- Use easy-to-use or widely-used CSCL tools where possible (e.g. LMS discussion boards, and to a lesser extent blogs and wikis)
- Plan for low bandwidth or limited online access; be flexible in when or how students use tools
- Ensure computer labs are available after hours for out-of-class collaboration; ensure labs are staffed during operating hours with knowledgeable support personnel
- Provide technical support for CSCL design and maintenance (e.g. knowledgeable staff that can create and maintain a WordPress.org blog on the university's server)

*Figure 5: Design principles for practitioners*

## 5. Reflections

As with any change project, this one did not proceed exactly as anticipated at the outset. As soon as the first author arrived in Oman, we realized our understanding of the Middle East and expectations of how to implement this research had to evolve. Furthermore, helping others to buy in to the importance of what we were trying to do was also a major challenge throughout this study. Doing educational design research as a graduate student is particularly difficult. Often the goals of a dissertation do not always align well with the intense collaboration, expertise, and large data collection efforts of successful educational design research projects. This was intensified by the fact that we designed the course while still in the United States, and then later travelled to Oman to implement it. This meant that the collaboration necessary from the beginning - people sitting around a table and drawing up a vision for the project - was not there. While everyone in Oman was extremely supportive, there was a sense throughout the study that this was the authors' study, and our Omani collaborators would accommodate

anything we felt was necessary, rather than this being *our* study where we accommodated whatever *they* thought was necessary.

This pointed to the fact that too often graduate dissertations are theory driven, and not needs driven, as was the case with this dissertation. Thus the lack of a bottom-up needs assessment to undergird the design can be seen as one of this study's greatest limitations. While much was done to work with local collaborators beforehand to identify appropriate interventions, from the beginning the project suffered from too much reliance on applying an innovative theory to a novel setting, without much regard of whether that intervention was truly necessary.

In the end, the constraints of working in Oman left us wondering if the students ever did build knowledge collaboratively or whether we had indeed fostered a community of learners. Had this study failed to meet its most fundamental goal? Additionally, did we make any lasting impact on education in Oman? Would these ideas die as soon as we stopped fanning the flames?

For us, Schoenfeld's (2004) commentary on four FCL projects that likewise lacked confidence in their results and which also faced major difficulties was instructive:

*Put these four sets of difficulties - finding big ideas, finding a plausible decomposition for purposes of jigsawing, designing non-standard instruction based on the jigsaw, and teaching in ways that foster the development of intellectual communities - together and you have a monumental challenge. This would be a major challenge for a seasoned design team and teachers who are well accustomed to 'reform'. To ask teachers without much design experience and relatively unseasoned facilitators to take on this challenge is to ask a great deal. The efforts of the four teams discussed here were little short of heroic, and their limited accomplishments should be judged accordingly. It should be understood that pioneering attempts demand heroic efforts, and that prototypes (both of process and of product) necessarily have lots of rough edges. What has been presented in this set of papers is a collective design experiment, where the goal was to create something important in order to examine and improve it. As has been seen, the outcomes fell short of expectations (for all of the reasons identified above). However, they can be considered improvements in both process and product over much traditional instruction, and catalysts for professional growth as well. On their own terms, those are non-trivial achievements. (p. 247)*

Reading this, we began to look at this project in a new light. Instead of seeing what went wrong in this study, we began to see what went right. That was when we saw the heroics of this project, and the value of our research.

### **What went right**

While not all students collaborated in the way we had envisioned, some did. Some students were prepared to take on this course and move forward their epistemology, knowledge, skills and perspective. We saw students arguing with other students and defending ideas. We saw students questioning the value of textbooks as the sole source of information. We saw students realizing their teachers were more their peers than their judges. We saw students creating, solving, producing, working together, and discovering new ways of teaching and learning. While not all students reached this level, some did. And several of those students mentioned that they wanted to apply these ideas in the future in their own teaching.

Additionally, students began to see a crumbling of the barriers that prevent information-sharing across gender. Male and female students collaborated online and shared ideas. We found

instances of students offering feedback, support, or inspiration to each other, from one gender to the other. For many students this was new, and for many, this was exciting.

While the change we saw was incremental, we did see change. The first author spoke with several faculty members about the ideas, and we saw many think about ways they could adopt them in their own classes. The fact that one faculty member tried them out in his own course, with a high degree of success, was enough to sense a change. In fact, we heard recently that one female faculty member at SQU even introduced in-class, face-to-face discussions between males and females, with some success. Change in any educational context is slow. But good ideas spread eventually, and as students become teachers, their students will experience change in their learning, and eventually Omani education will include more of the kinds of learning experiences that will prepare Omani knowledge workers for the future.

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## Promoting Academic Research Writing with South African Master's Students in the Field of Education

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# 40. Promoting academic research writing with South African master's students in the field of education

Cilla Dowse & Sarah Howie

## Abstract

*The aim of this research, conducted within the framework of design research, sought to design and develop an academic research writing intervention implemented during the proposal stage of study in a master's programme. Underpinned by the New Literacy Studies and applying a framework for the teaching of academic writing, the intervention supported by a research triad working within a community of practice was designed to meet the unique needs of the students in the South African context. Factors such as educational background, English language proficiency and underpreparedness for graduate study are challenges which need to be overcome. Emerging from the phases, this study identified characteristics of an intervention for the promoting academic research writing which would best support master's students in education.*

## 1. Introduction to the research

Graduate students do not always know how to write and struggle to successfully complete the writing of the research proposal and the dissertation or, despite generally being able to complete the modules making up the programme. Research nationally and internationally on student writing (Hendriks & Quinn, 2001; Kamler & Thomson, 2004; Leibowitz, Goodman, Hannon, & Parkerson, 1997; Lillis & Turner, 2001; Wadee, Keane, Dietz, & Hay, 2010), reinforced by a pivotal study by Torrance and Thomas (1994), revealed that students' inability to complete their research is often a result of writing-related issues, which thus jeopardises academic success and completion of studies, particularly for those students for whom English is not a first language.

Amongst the many educational changes within the South African context since 1994 and the move to a democratic regime, many more mature professionals have been motivated to study further as is evidenced by the increasing numbers of students registering for graduate studies (Giannakopoulos & Buckley, 2009). This "widening [of] the social base of higher education includes, *inter alia*, adult learners" (Walters & Koetsier, 2006, p. 98) who tend to be older, mid-career professionals. Such access to higher education has resulted in massification involving "the establishment of a multicultural, multilingual student body" in sharp contrast to the pre-1994 higher education context which was "monocultural and monolingual" (Bouhey, 2000, p. 281). However, coinciding with this greater access to higher education in South Africa, problems of throughput<sup>1</sup> have arisen. South African studies have revealed a range of throughput figures ranging from 10 to 69% (Cronje, 2007; Holtzhausen, 2005; Le Grange, 2002; Mouton, 2007), although in Watson's study, the findings revealed an extremely wide range of completion rates

<sup>1</sup> *Throughput* is a term used to describe the proportion of student success rate from first year to final qualifying year - graduation rate may also be used (Watson, 2008).

that “varied from 0 per cent (in the worst instance) to 74 per cent (in the best case)” (2008, p. 735) depending on the institution and the programme.

Research conducted nationally has revealed that many of these ‘new’ students are under-prepared and ill-equipped for successful graduate research. Factors, noted in South African literature, include the inability to write coherently as students lack basic writing skills and academic literacies (Esterhuizen, 2001; Hendriks & Quinn, 2001); being unprepared for the rigours of graduate study by not being equipped with the vital academic literacies (Koen, 2007; Netswera & Mavundla, 2001; Van Aswegan, 2007) and a lack of knowledge and understanding of research compounded by a low level of research development (Netswera & Mavundla, 2001). Working within the framework of design research, conceptualising and developing an intervention was an attempt to promote academic research writing<sup>2</sup> proficiency, in order to assist students develop as confident and independent academic research writers within a specific discipline.

The research question for this study is: *What are the characteristics of an intervention for promoting academic research writing which will best support master’s students in education in the proposal stage of their research?*

## 2. Reviewing the literature on academic writing

Even if institutions acknowledge that students are ill-equipped for graduate study, they tend to assume that these skills or proficiencies will implicitly or osmotically develop through the research and supervision process. However, the task of negotiating entry into a discourse community is more complex than either students or lecturers sometimes think, particularly as, in the South African context, many students registering for graduate studies in education are full time teachers, were educated under the previous regime which historically comprised their education and may be returning to further studies after some time.

The teaching of academic writing has been the cause of much discussion. A generic approach to the teaching of writing has been criticized as divorcing writing from the thinking within the field and thus the generic vs. discipline-specific approach to the teaching of writing is an issue of debate. For this study, Lea and Street’s (1998) research into student writing in higher education which identified three approaches being used within an overall academic literacies model for the teaching of academic writing, is considered. Moving from an autonomous view of literacy to an ideological their approaches included *the study skills model*, *the academic socialisation model* and *an academic literacies model*. Ivanič’s development of a *Discourses of Writing* framework (Ivanič, 2004) which outlines six approaches for the teaching of writing is also incorporated into this study.

Ivanič’s first approach, *skills approaches* aligns with Lea and Street’s study skills approach which is underpinned by the notion of seeing writing as a set of skills. A *creative self-expression approach* views writing as literature to be enjoyed and draws on learning to write from personal experience. The *process approach* takes into account both cognitive and procedural processes, while a *genre approach* focuses on the product shaped by the writing event but is dependent on the “linguistic characteristics of different text-types” (Ivanič, 2004, p. 233). This last approach falls within Lea and Street’s academic socialisation model where students are enculturated into the discipline and the discourse in order to write appropriately. The penultimate approach, *the functional approaches*, is rooted in the social context where writing is seen as communicating for a particular purpose, making use of cognitive processes and the application of academic

<sup>2</sup>*Academic research writing* is a term coined for this research which incorporates academic writing, discipline-specific content knowledge and research methodology knowledge.

literacy. It is also within this approach that students find themselves with the writing of their research. This approach aligns itself with the New Literacy Studies as well as with Lea and Street's academic literacies model. Finally, a *critical literacy approach* rooted in a socio-political discourse and one into which it is hoped students would move, has consequences for the writer who needs to draw on discourse and genre in order to represent the world in a specific way. In Ivanič's framework it seems as though the approaches to the teaching of writing in higher education have been incorporated into one cohesive framework which is not static but in fact, it moves on a continuum depending on the approach needed and utilized in specific contexts or at particular times. As such, the teaching of academic writing should be seen as an integral part of disciplinary learning for all students (Mitchell & Evison, 2006) with the "practice of writing being viewed as central to [their] research" (Catterall, Ross, Aitchison, & Burgin, 2011, p. 1). Teaching therefore should take place within the social context of its disciplinary community (Hewings, 2004), and be based on a construct of academic literacy (Weideman, 2003).

However, the issue of language in the South African context needs to be raised. Students, on the one hand, are being seen as under-prepared and lacking research knowledge and skills (Netswera & Mavundla, 2001, p. 154) while on the other hand, are hindered by language (where English is not a first or home language) and by their education preparation. Students may be fluent in spoken English but may not have developed the kind of language (both oral and written) necessary for developing conceptual understanding at graduate level. Taking note of the theory of language acquisition - Basic Interpersonal Communicative Strategies (BICS) and Cognitive Academic Language Proficiency (CALP) (Cummins, 1979) - can perhaps assist language practitioners in understanding the challenges that students face in developing academic research writing and academic literacy proficiency particularly if they are not English first language speakers. This is the case in the South African context, where nine African languages as well as English and Afrikaans make up the official languages of the country. Drawing from a review of the literature (see Dowse, in press for full review), the conceptual framework is underpinned by key theoretical elements: firstly, systems theory (von Bertalanffy, 1968) with its input, process and output system; secondly New Literacies theory and finally, the framework of Ivanič. The input of this framework in addition to policy and the master's programme, takes into account students' social capital, educational backgrounds, English language ability, academic literacies and academic writing proficiency.



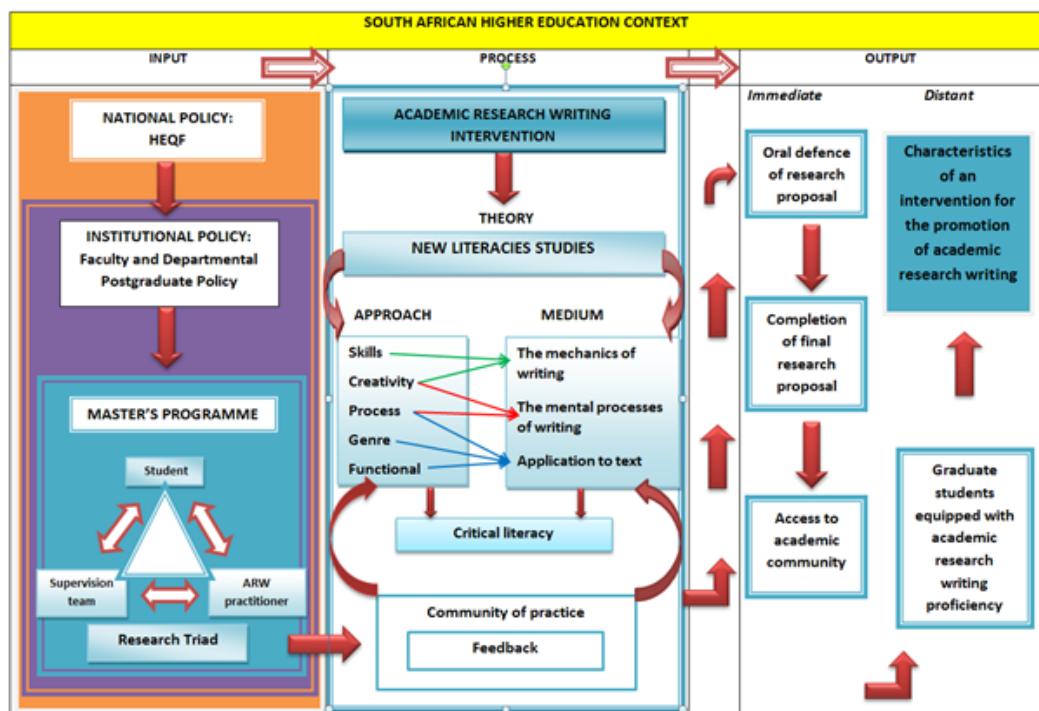


Figure 1: Conceptual framework for the academic research writing intervention (Dowse in press)

The *process* describes the academic research writing intervention, the theories underpinning it and the approaches used to facilitate its implementation. The intervention, informed by the New Literacies Studies theory incorporates a range or continuum of approaches drawn from Ivanič's *Discourses of writing and learning to write* (2004). Each of the approaches has an influence on the medium: the skills and creativity approaches apply to the mechanics of writing, the mental processes involved in writing draw on the creativity/self-expression, process and genre approaches while, application to text or the writing event is influenced by the genre and functional approaches. Although the five approaches are situated on a continuum with teaching moving between each of the approaches, the aim in the teaching of writing is for the student to work within a critical language approach. A community of practice is formed with the research triad offering support using the giving and receiving feedback as a mode.

The *output* is portrayed both as immediate, where students, in successfully defending the research proposal and finally, completing a final version of that document, gain access to the academic community, thereby illustrating the effectiveness of the intervention; and more distant, where the outcome is that the students, once they have successfully defended their research proposal, are considered being equipped with appropriate academic research writing proficiency and thus can move forward confidently into the academic community.

### 3. The design of the research

As identified earlier, the educational problem being investigated was the lack of academic writing proficiency manifesting in poor academic literacies found in graduate students, which resulted in students being underequipped for study at graduate level. The study took place within a specific master's programme in education where the aim of the intervention was to support the students in the promotion of academic research writing through the first phase of their research, that of conceptualising their study, and writing and defending their research

proposals, particularly as the research proposal is seen as having a gatekeeping function (Cadman, 2002). In order to conceptualise the study, the main research question is: *What are the characteristics of an intervention for promoting academic research writing which will best support master's students in education in the proposal stage of their research?*

Thus, in conceptualising the design for this study, design research, “the systematic study of designing, developing and evaluating educational interventions ... as solution for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them” (Kelly, 2003; Plomp, 2009, p. 13; Van den Akker, 1999), was considered the most appropriate research design. As a further argument to support design research’s applicability for this study, Plomp explains that one of the aims of design research is the development of an intervention to address an issue but for which few guiding principles or ready-made solutions or guidelines have been found (2009, p. 17) and where problems are addressed for which no “how to” guidelines exist (2009, p. 13). The paradigm of pragmatism of “what works?” aligns with Plomp’s notion above and thus, this research is situated in the pragmatist paradigm. Pragmatic researchers, whose research occurs in social, historical, political and other contexts, look to *the what* and *how to* research based on its intended consequences – where they want to go with it (Creswell, 2007, p. 23) focusing on the most appropriate way to answer the question irrespective of whether qualitative or quantitative methods are used (Johnson & Onwuegbuzie, 2004; Onwuegbuzie & Leech, 2005). In addition, this study has a “reformist agenda, aiming to find what works within the specific cultural contexts ....and appropriately inform educational practice...” (Purser, Skillen, Deane, Donohue, & Peake, 2008, p. 2), which aligns itself with the National Plan for Higher Education in South Africa.

Design research characteristics have been described in general through investigation into research reports (Barab & Squire, 2004; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003; Kelly, 2003, 2004; Reeves, 2006; Reeves, Herrington, & Oliver, 2005; Shavelson, Phillips, Towne, & Feuer, 2003; Van den Akker, 1999; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). These characteristics were seen as appropriate for this research into the design and development of an intervention for the promotion of academic research writing as they are (Van den Akker et al., 2006, p. 5):

- *Interventionist* in that they involve designing interventions *such as creating a learning intervention for graduates in education, an academic research writing intervention.*
- *Involvement of practitioners* entails the active participation of practitioners at various stages of the intervention, thus *including the students with a team of supervisors and an academic research writing practitioner who focuses on academic writing.*
- *Iterative* in that research takes place *through repeated cycles of design, implementation, evaluation and revision to ensure that the academic literacies and academic research writing needs of the graduates were being met by this developmental intervention.*
- *Process-focused* in that they seek to understand both *the learning process and the effect of a designed intervention on that learning, and in this case, the development and writing of the first stage of the dissertation.*
- *Utility-oriented* in that they aim to produce usable knowledge for *explaining how the intervention functions in the context of graduate studies within the field of education.*
- *Theory-driven* in that theoretical assumptions, which *guide the design of the intervention for the promotion of academic research writing, are tested with the intention of developing guidelines or design principles for future use through the cyclic design-implementation-evaluation-redesign of the intervention.*

This research follows the typical design research pattern being cyclical and iterative, consequently consisting of phases: a *preliminary phase* (Phase 1) a *prototyping phase* (Phase 2) and an *assessment phase* (Phase 3). The process for this study therefore follows three phases and incorporates eight operational cycles within these phases, with the relevant research questions and is outlined in the Figure 2 below.

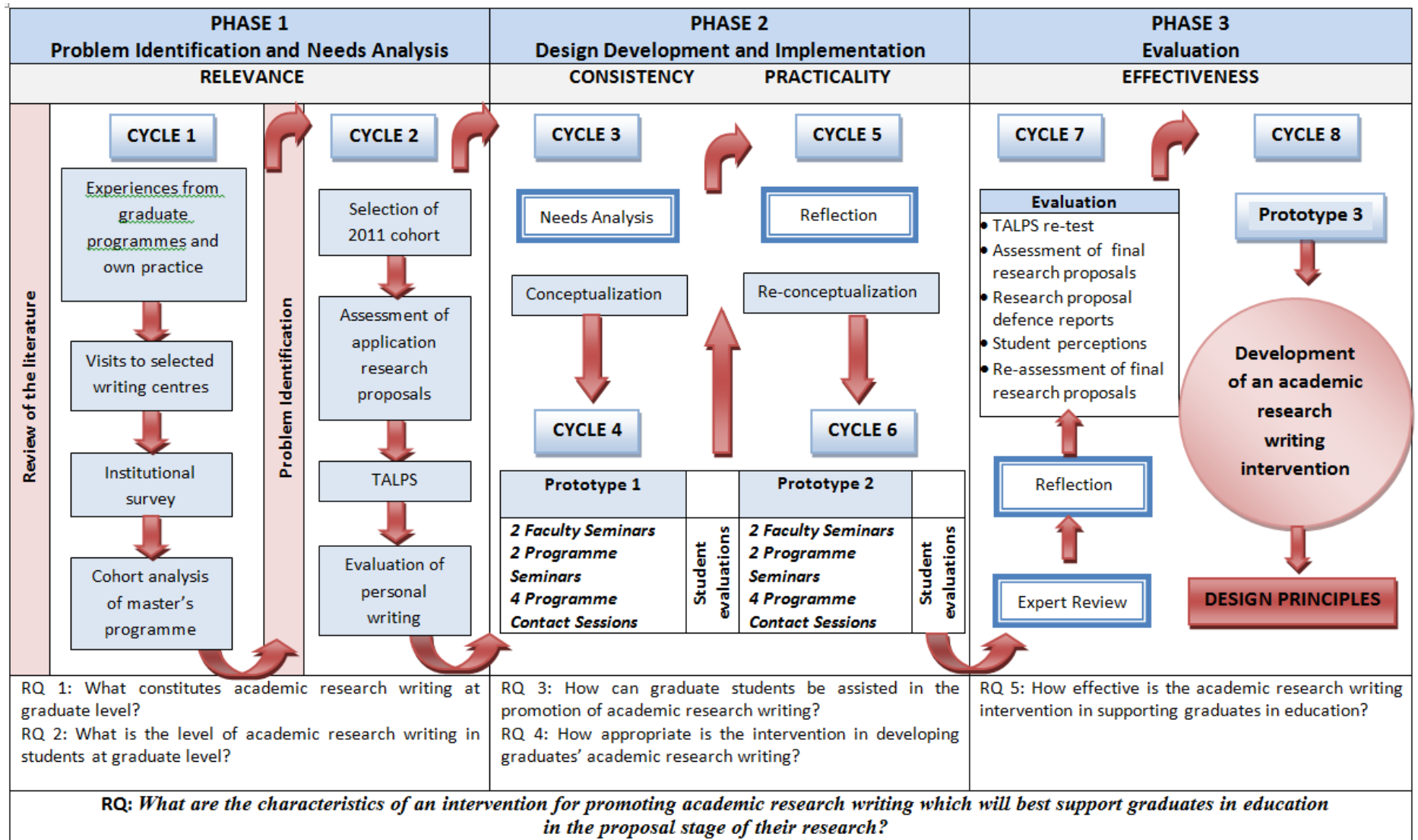


Figure 2: Design research model for the development of an academic research writing intervention (informed by Archer, 2010) (Dowse, in press)

In developing further research questions to operationalize the main research question (see Figure 2), Nieveen's (2007) criteria for high quality interventions - *relevance*, *consistency*, *practicality* and *effectiveness* - were considered. The criterion of *relevance* is applied to the first two secondary questions:

1. *What constitutes academic research writing required at graduate level?*
2. *What is the level of academic research writing of students entering graduate study?*

These research questions were developed to gain an understanding of what academic research writing comprises and the academic research writing level at which students are performing when entering graduate study. These two questions are addressed in Phase 1 of the research design and investigate the relevance of the intervention: "there is a need for the intervention and its design to be based on state-of-the-art (scientific) knowledge" (Nieveen, 2007, p. 94).

An extensive review of the literature and through an analysis of the context, assisted in coming to an understanding of what constitutes academic research writing at graduate level, as well as the teaching of academic writing and how students are assisted in the promotion of their academic research writing. Drawing from this understanding, a conceptual framework for the study was developed (see Figure 2) which provides a lens for the design and development of the content of the intervention, as well as a lens for viewing the findings.

Drawing from the theory as well as practice, the next research question interrogates ways in which graduates can be assisted but it also takes into consideration the criterion of *consistency* which seeks to ensure that the intervention is logically designed.

3. *How can graduate students be assisted in the promotion of academic research writing?*

In putting an intervention into place, its *practicality* needs to be ascertained. Firstly, the *expected* practicality where "the intervention is expected to be usable in the settings for which it has been designed and developed" should be determined. Thereafter, the *actual* practicality where "the intervention is usable in the settings for which it has been designed and developed" also needs to be established (Nieveen, 2007, p. 94). Thus, the practicality of the intervention is addressed through the following research question:

4. *How appropriate is the intervention in developing academic research writing?*

If an intervention is put in place, its *effectiveness* should be ascertained but again *the expected effectiveness*: "using the intervention is expected to result in desired outcomes" and *actual effectiveness*: "using the intervention results in desired outcomes" (Nieveen, 2007, p. 94) were considered. Thus, Question 5 draws on empirical research conducted with the sample of the 2011 cohort of master's students and the evaluation of the academic research writing intervention which drew on a number of approaches such as constructivist teaching, the proactive role of the teacher and productive instructional activities within a specific classroom culture (Van den Akker et al., 2006, p. 50). The final research question then, evaluates the intervention:

5. *How effective is the academic research writing intervention in supporting graduates in education?*

In this research, one cohort was sampled for participation in each of the phases of this research. Participants for this study comprised graduate students registered with a faculty of education for a specific master's programme during 2011 (see Table 1) and were thus selected purposively. The students were assured of anonymity with pseudonyms being used in place of their names (for example, P1 – P.10). The supervision team consisting of an experienced

supervisor and three novice supervisors plus the academic research writing practitioner were also part of the sample.

*Table 1: List of students and their profiles*

Participant	Race	Gender	Age	Home language	Other languages spoken and written
P.1	Black	Female	40	Setswana	English *
P.2	Black	Male	42	Xitsonga	English, Afrikaans, Setswana, Sepedi
P.3	Black	Male	47	siSwati	isiZulu, English
P.4	Black	Male	44	isiZulu	English, Afrikaans, Sesotho, Xitsonga, Setswana
P.5	White	Female	25	Afrikaans	English
P.6	Black	Female	43	Sepedi	English, Setswana, Sesotho, Afrikaans
P.7	Black	Male	44	Setswana	English *
P.8	Black	Male	36	Tshivenda	English, isiZulu, Sepedi
P.9	Black	Female	41	Khoi-Khoi	Afrikaans, English
P.10	White	Female	24	English	French, Afrikaans

\* missing data

As previously discussed, the majority of students do not have English as a first language and this needed to be noted and taken into account when designing the intervention.

### **The academic research writing intervention**

How the main research question was operationalized is discussed in the phases below where tables (see Tables 3-5) outline data collection strategies and research participants. The study was conducted over an eighteen-month period and comprised a variety of instruments, data collection strategies and data analysis techniques across the three phases of the research (see Figure 2). Cognisance must be taken that the findings of each of the phases not only answer the research question specific to that phase but they inform the subsequent phase.

#### ***Phase 1: Problem identification and the needs analysis***

In Phase 1, Cycle 1 comprised a number of activities in order to identify the problem through practice: experience from graduate programmes and own experience, visits to selected writing centres situated in higher education institutions in South Africa to ascertain what is done to support graduate students, a cohort tracking and analysis of an earlier master's programme and finally, an institutional survey. These activities informed the extensive review of the literature which assisted in addressing the research question of *What constitutes academic research writing required at graduate level?*

Cycle 2, which identified the problem through a needs analysis, answered the research question of *What is the level of academic research writing in students at graduate level?* and was addressed by the three data collection strategies listed below.

Table 3: Data collection strategies and data analysis techniques for Phase 1

Data collection procedures: phase 1 cycles 1+2			
	Data collection	Instrument	Research participant
1	Assessment of application proposals	Rubric for assessment of application proposals	Supervisor and researcher
2	Test for Academic Literacy Proficiency Study (TALPS)	TALPS assessment instrument	Practitioner from Centre for Academic Literacy at the University
3	Evaluation of personal writing	Response to personal writing form	Researcher

### 1. Assessment of application proposals

The research proposals submitted by the students as part of their application for entry into the master's programme were assessed to elicit a baseline assessment of academic research writing and application of content knowledge and methodology. Taking into account a rubric by Carstens (in Carstens & Fletcher, 2009) and one developed by the researcher and a colleague and reviewed by an expert, a rubric was designed for use in assessing the proposals. The assessment rubric, an instrument comprising 25 items, was grouped into eleven categories which apart from academic writing style, mirrored the research proposal. A 5-point scale was used for each item with 4 representing *excellent*, 3 *good*, 2 *fair*, 1 *poor/incomplete*, and 0 representing *missing*. All items resulted in an accumulative score of 100.

These proposals were assessed by two assessors with the same rubric being used in assessing the initial research proposals, again during the course of their development and finally, once the proposal had been successfully defended. However, when individuals score tests, scorer reliability needs to be taken into account (Gay, Mills, & Airasian, 2009) particularly when the assessment is open ended as opposed to a one-word answer. Therefore, consistency needed to be developed between the scorers. In this case, once the assessment was complete, the scorers discussed discrepancies and in some cases, went back to the proposals to discuss their assessment to ensure inter-rater reliability.

The results of the assessment gave the designers not only a good indication of the students' academic research writing ability but also highlighted the fact that the students had little understanding of the genre of research proposal writing and what was expected in its writing. What was also highlighted was the students' gap in discipline-specific content knowledge and research methodology knowledge as well as English proficiency and writing ability. This valuable information fed into the design and development of the intervention (Phase 2).

### 2. Test for Academic Literacy Proficiency (TALPS)

Once students were registered for the master's programme, they sat the Test for Academic Literacy Proficiency (TALPS<sup>3</sup>). TALPS is comprised eight sections assessing various aspects of academic literacy such as ability to develop coherence with scrambled text, visual and graphic literacy, knowledge of general academic vocabulary, ability to recognise different written text types, reading comprehension, academic literacy abilities, grammatical knowledge of English and finally, the ability to produce a written academic text (Butler, 2009).

<sup>3</sup>TALPS, a language test used in 4-5 higher education institutions in South Africa, was considered to be a good baseline assessment which would, in conjunction with other initial assessments, would give some indication of the level of academic literacy.

The code assigned to each student (on a 1 - 5 scale) gave an indication of those students at-risk in terms of academic literacy proficiency and alerted the developers of the intervention of issues to incorporate into the design of the intervention. Two students were reported as at *extremely high risk* (Code 1), one at *high risk* (Code 2), two *at risk* (Code 3) while the remaining 4 students tested were seen as being *low risk* (Code 4). No student was categorized as being *at no risk*. Further analysis of the results for various sections of the test offered a more in-depth idea of aspects to include in the intervention to assist the students in acquiring and developing academic literacies, such as developing academic discourse, in-depth reading and comprehension in discipline specific areas and the writing of text, considering academic conventions such as argument and referencing. These results were also used as input into the intervention, in addition to serving as a baseline for students' academic literacy at the beginning of the intervention.

### 3. Evaluation of personal writing

As a final baseline assessment to ascertain how the students wrote when not under pressure and in an informal style (see Elbow, 1997), they were asked to submit personal writing where they wrote about themselves, their families, their profession and their motivation for entering into the master's programme. The evaluation of the personal narrative occurred within the three categories of *golden thread*, *structure* and *language application* which covered both higher order concerns as well as lower order concerns (McAndrew & Reigstad, 2001) as illustrated below:

1. *Golden thread* - aligned with matters that reach beyond the text itself.
2. *Structure* - aligned with matters of content.
3. *Language application* - aligned with matters of form.

Problems that were identified in the students' personal writing included the functional use of:

- concord - non agreement between subject and verb;
- prepositions - incorrect choice of preposition;
- pronouns - incorrect gender, inconsistent use;
- determiners - use of articles;
- possession - use of apostrophe;
- contractions - use of apostrophe;
- vocabulary use - incorrect use of words/ unawareness of more appropriate word;
- punctuation;
- correct spelling;
- critically reading text and self-editing.

Findings from these three baseline assessments gave an indication of the probable level of writing proficiency and given the very basic nature of the grammatical errors, a good indication of what aspects or conventions of academic research writing needed to be included in the intervention in order to promote their writing.

### **Phase 2: Design, development and implementation of the intervention**

In design, development and implementation in Phase 2, data was collected to address Research Questions 3 *How can graduate students be assisted in the promotion of academic research writing?*

Cycle 1 led me to examine my own practice in student support and development as well as what is happening with graduate support and development at various universities in South Africa in order for it to align with the Higher Education Framework, which specifies the competency levels that students should attain at various levels of study. Cycle 2 helped



ascertain that the students were lacking in the relevant academic literacies and academic research writing proficiency needed for success at this level. It seemed that even though some students had come through an honours programme that was discipline-specific, they were not well equipped enough, as evidenced by the application proposals, TALPS and the personal writing assessment.

An extensive review of the literature led to an understanding of what constitutes academic writing at graduate level with an investigation of various models of the teaching of academic writing (see Figure 1) which informed the design and development of the academic research writing intervention (Cycle 3). Van den Akker's components of curriculum development (Van den Akker, 2003) rationale or vision, aims and objectives, content, learning activities, teacher role, materials and resources, grouping, location, time and assessment, which suggest ensuring that a fine balance is developed and maintained between and within each of the components, guided the design of the intervention. In addition, 21<sup>st</sup>Century skills, namely *ways of thinking*, *ways of working*, *tools for working* and *living in the world*, were incorporated into the pedagogy of academic research writing and thus in the intervention (Binkley, Erstad, Herman, Raizen, Ripley, & Rumble, 2010; Plomp, 2011). Working with adult learners highlighted theories of learning appropriate for the teaching of adults (Andragogy) (see Bezuidenhout, Van der Westhuizen, & de Beer, 2005; Gravett, 2000; Merriam & Caffarella, 1991/1998). The education of adults should be active, self-conscious, self-directed (Brown & Campione, 1994) but importantly, learning, drawing on prior knowledge and experience (Paltridge, 2001) and based on the zone of proximal development (ZPD) (Vygotsky, 1978), should be a process of discovery and re-discovery through a cyclical, iterative process.

The final aspect that was considered was a values system to ensure that relationships are built on trust, and that importantly, interplay of empathy, respect, fairness, responsibility and openness could develop between the students, as well as between the students and the supervision team and academic research writing practitioner.



Figure 3: Values wheel (Austin, 2010)

These considerations for design form the underlying theory behind the intervention. However, the intervention was driven by a variety of approaches to the teaching of academic research writing (see conceptual framework) as well as modes of working - instead of the student working in a dyad with the supervisor, a triad was formed with the student, the supervision team and the academic research writing practitioner working within a community of practice. To facilitate learning and the development of writing, the mode of giving and receiving feedback both from

the team, the practitioners and the students themselves was utilized and incorporated into the intervention. In the re-conceptualization cycle (Cycle 5), similar principles were also applied. The intervention implemented in Phase 2 ran over two semesters and was made up of four faculty seminars which comprised lectures on a variety of generic topics relating to research, four programme seminars which focused on discipline-specific content and methodology specific to the discipline and eight contact sessions taking the form of interactive workshops, focused on the conceptualising, design and writing of the research proposal, culminating in the proposal defence.

Research question 4 *How appropriate is the intervention in developing academic research writing?* informed data collection for these cycles and is tabled below:

*Table 4: Data collection procedures for Phase 2*

<b>Data collection procedures: Phase 2 cycles 4 and 6</b>			
	<b>Data collection</b>	<b>Instrument</b>	<b>Research participant</b>
1	Evaluation of faculty seminars and programme seminars	Student questionnaire	Students
2	Evaluation of contact sessions	Student evaluation forms	Students
3	Assessment of initial and developing research proposals	Rubric for assessment of proposals	Supervisor and researcher
4	Student progress reports	Progress report sheet	Supervision team
5	Assessment at the mock defence	Assessment form	Supervision team

*1. Evaluation of faculty seminars and programme seminars*

A questionnaire sent electronically to students evaluated faculty seminars and programme seminars in terms of what was learned and the value of the sessions. Results of this evaluation are discussed in the Phase 3.

*2. Evaluation of contact sessions*

Throughout the implementation of the intervention, students completed evaluations electronically after each of the sessions. The evaluation form, specifically designed for each session, most often consisted of a descriptive written explanation of what was experienced, how they found the experience and if either helped or not with their academic research writing process. Content analysis was used whereby all text was coded, the codes were then grouped into categories and assigned a theme or title, although in this case, categories represented descriptions and critiques. These “thick” descriptions (Merriam, 1998, 2002) were used in writing up of this phase (see Chapters 5, 6 and 7 Dowse in press).

The findings emanating from this analysis revealed that the students regarded a structured programme fundamental at this stage of their graduate studies as it was developmental as well as incremental. As academic writing cannot be taught in a vacuum (see literature), academic research writing was being developed predominantly within a genre approach where the writing of the various sections of the research proposal was done progressively over the course of a number of contact sessions. However, the teaching of academic research writing moved along the continuum, discussed in Ivanič’s framework, as needed. Contact sessions used the mode of

working within a community of practice with the giving and receiving of feedback which fed into the learning of the students and ultimately, the development of their writing.

The timetabled contact sessions, conducted over a three-hour period, received favourable evaluation from the students particularly as they facilitated and promoted interaction between the students on a regular basis, drawing on the approaches to the teaching of academic writing which advocates working within a community of practice and using feedback to inform development.

### *3. Assessment of research proposals*

After Semester 1's intervention and after determining student progress, the students' research proposals were assessed by the same assessors using the same rubric used in the assessment of the application research proposals. Given that the numbers being assessed were small, a non-parametric test was used to determine development of academic research writing competency. The Wilcoxon signed-rank test was used where probability values (p-values) lower than 0.05 indicate that there is a significant improvement. The difference between the application and the initial proposals, as well as the initial and the developing research proposals, was statistically significant ( $p = 0.027$ ,  $p < 0.05$  and  $p = 0.018$ ,  $p < 0.05$  respectively). Thus, an improvement in the writing of the proposal was noted even though the implementation of the intervention was in its early stages.

### *4. Student progress reports*

Student progress reports were completed twice a year to track the students' progress through each of the semesters, ensuring that they were working in line with the developmental programme. By the end of the first semester, most students had managed to submit an initial and a developing proposal (see above). By mid-Semester 2, the students had completed their research proposals and were preparing to participate in a mock defence.

### *5. Assessment at the mock defence*

In preparation for the defence of their research, students presented their proposed research in a mock defence presentation session. The supervision team consisting of the experienced supervisor, two novice supervisors and the academic research writing practitioner made up the panel. An assessment rubric was created for use by each panel member during each of the presentations, which were supported by PowerPoint presentations. After each presentation, panel members individually gave feedback which was drawn together by the panel leader and summarized for the student. Assessment of the mock defence took the form of analysing the summarized responses to identify issues which still needed to be addressed with and by students in preparation for their proposal defence.

### ***Phase 3: Data evaluation of the intervention***

Data collection in the final phase, Phase 3 Evaluation, aimed at addressing the final research question: *How effective is the academic research intervention in supporting graduates in education?* The phase's data collection instruments are summarized below:

Table 5: Data collection procedures for Phase 3

Data collection procedures: Phase 3 cycles 7+8			
	Data collection	Instrument	Research participant
1	Expert review	Expert review form	Two expert reviewers
2	Test for Academic Literacy Proficiency Study (TALPS) (re-test)	TALPS assessment instrument	Practitioner from Centre for Academic Literacy at the University
3	Assessment at the research proposal defence	Record of Doctoral and Master's Proposal Defence	Chairperson and defence panel
4	Assessment of final research proposals	Rubric for assessment of proposals	Supervisor and researcher
5	Student questionnaire	Student questionnaire	Researcher
6	Student interviews	Interview schedule	Researcher
7	Re-assessment of final research proposals	Rubric for assessing academic research writing proficiency	Expert reviewer 2

#### 1. Expert review

Two expert reviewers<sup>4</sup> were approached to review the intervention firstly at the end of Semester 1 and secondly, at the end of Semester 2. A schedule was given to the reviewers for consideration when reviewing the programme, taking into account alignment with the HEQF and institutional policy requiring the need to design, develop and defend a master's research proposal within the first year of study. The experts were asked to offer criticisms and critique, comment on omissions as well as make suggestions for improvement. Generally, comments were positive; however, the main critique was that more focus seemed to be given to the teaching of discipline-specific content and research methodology rather than academic research writing. It was suggested that more attention is paid to promoting academic research writing using the discipline-specific content and research methodology as the vehicle.

#### 2. Test for Academic Literacy Proficiency Study (re-test)

A re-test of TALPS, seen as a post-intervention measure of their academic literacy competency, was conducted midway through the students' second year of study. The Wilcoxon signed-rank test was used to assess the differences between sets of scores from the same participants and applied in assessing the difference between the pre- and post-intervention tests (see Figure 4) to highlight any development of academic literacy.

<sup>4</sup>Considered for their expertise in academic writing, research methodology and supervision of graduate students.

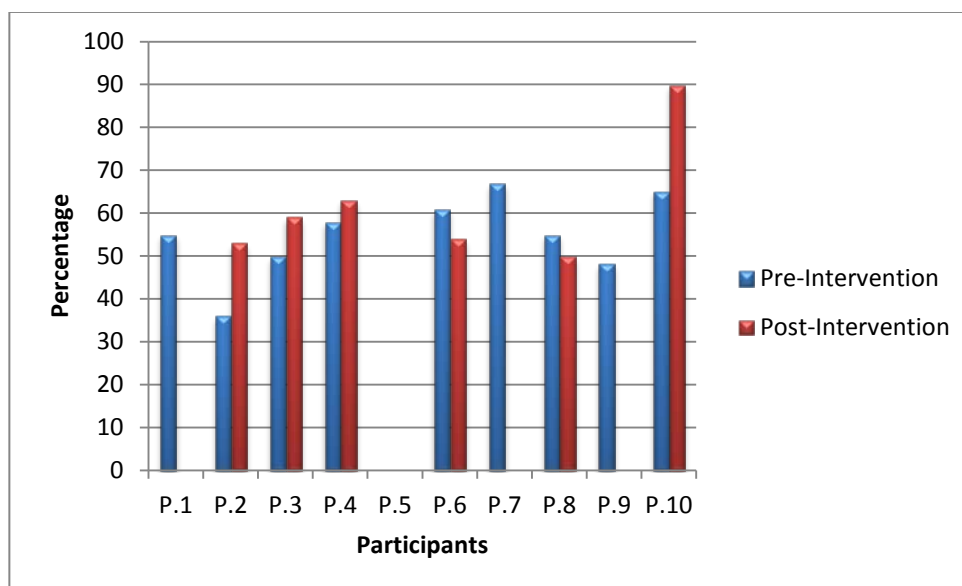


Figure 4: Pre- and post-intervention comparison of TALPS results

No statistical difference was found and therefore no overall improvement in the scores was noted; however, a pre- and post-intervention comparison of individual participants revealed a considerable improvement with Participants 10 (+25%) and 2 (+17%).

### 3. Assessment at the research proposal defence

On an appointed day, the students presented their research proposal presentations to a panel consisting of the chairperson and representatives from the Department as well as critical readers. Assessment data, collected from the defence presentation, consisted of the *Record of Doctoral and Master's Proposal Defence: 2011* completed by the chairperson after a collaborative discussion with the critical readers and the Departmental representatives. Assessment of the research proposal defence takes the form of awarding the student one of the following ratings:

Table 6: Rating scale and decision for research proposal

Rating	Decision
1	Proposal is approved
2	Proposal is approved with minor corrections (candidate needs to make minor revisions to the satisfaction of his/her supervisor)
3	Proposal is provisionally approved (candidate needs to make major revisions to the satisfaction of his/her supervisor and two panel members)
4	Proposal is not approved (candidate needs to defend again or resubmit to the supervisor, chair of the proposal defence and one other academic)
5	Proposal is referred to the Graduate Committee for consideration

Of the 10 students originally registered for this programme, three had de-registered. Thus, seven students defended their proposals successfully with six being awarded a rating of 2 where minor changes had to be made and one student being awarded a rating of 3 where major revisions were needed.

#### 4. Assessment of final research proposals

After the research proposal defence, students' final and revised research proposals were once again assessed by two assessors against the same rubric used for the earlier assessments which gave a post-intervention indication of the standard/proficiency of academic research writing. Statistically significant differences from the developing research proposal to the final product ( $p=0.017$ ,  $p<0.05$ ) and between the application research proposals and the final research proposals ( $p=0.039$ ,  $p<0.05$ ) were noted. The Friedman's two-way analysis of variance by ranks confirms the statistically significant differences between all four proposals ( $p=0.002$ ,  $p<0.05$ ).

This result is important information for judging the success of the intervention. The empirical data suggests that there is a significant difference between each of the proposals. Furthermore, content analysis undertaken by the supervision team and the academic writing practitioner concludes that the students, through the process, developed a meta-cognition firstly, about the genre in which they were working, secondly, about the process of their writing and finally, the varying cognitive processes involved. Thus, their writing improved, coherence was achieved, and readability was established. We can therefore conclude that the intervention was successful in supporting the students through the process of writing and defending their research proposals.

#### 5. Student questionnaire

At the end of the academic year, a questionnaire required students to evaluate the academic research writing intervention particularly taking into account faculty seminars and programme seminars which were put in place for students to develop both content and research methodology knowledge. The questionnaire, accompanied by a covering letter, was emailed to participants for completion at home/work.

After receiving the electronic submission of the questionnaire and data capturing, mean scores were calculated to evaluate the seminars specifically for the categories resulting in an overall average out of a possible 4. The overall average results of the evaluation for the faculty seminars and the programme seminars are summarized in Tables 7 and 8 below (see Dowse in press).

Table 7: Mean scores for evaluation of faculty seminars

Faculty Seminars	Relevance for own dissertation	Addition of new information	Understanding of next steps in the research process	Increase in knowledge
Overall Average	2.83	2.87	2.75	2.79

Students, during the course of their studies, are expected to attend faculty seminars. The students however, found that these generic seminars were of lesser value than the programme seminars, scoring each seminar according to a particular category below 3.0 out of a possible 4. In contrast, the evaluation of the programme seminars, whose development was based on the results of the needs analysis and thus more tailored to the students' needs, elicited a higher overall evaluation.

Table 8: Mean scores for evaluation of programme seminars

Programme Seminars	Relevance to level of study	Relevance for own dissertation	Understanding of suitable approaches to research	Addition of new information	Understanding of next steps in the research process	Increase in knowledge
Overall Average	3.84	3.47	3.60	3.64	3.52	3.68

Although relevance for own dissertation averaged out at the lowest (3.47), it seems as if the students valued the content of each of the sessions and as part of a structured programme in assisting them in developing both discipline-specific content knowledge and research methodology knowledge which would form the foundations for study in this particular field of education.

#### 6. Student Interviews

Interviews were conducted with each of the seven remaining students to engage in a discussion and elicit responses on how the students viewed the effectiveness of the intervention, particularly focusing on their development as writers and researchers. Students were questioned on the writing processes that they followed, the challenges to be overcome and a reflection on the intervention particularly after successfully defending their proposals, issues about academic research writing which had arisen during the defence process and the finalization of their research proposals. On average, the student interview reinforced the value of the intervention in promoting academic research writing, with students highlighting that the opportunity to interact with other graduate students scaffolded their learning and allowed them time to become enculturated into the academic discourse, developing a meta-cognition of the writing process and the conventions of academic research writing.

#### 7. Re-assessment of final research proposals

Assessment of final proposals by two assessors, which gave a score, indicated that there was compliance with what was required for students to successfully defend their proposals. However, it was felt that the academic research writing proficiency was not as developed as it needed to be to take the students into the second stage of their studies. Expert reviewer 2, using assessment guidelines which take into account aspects such as tone, register, argument, coherence, hedging, use of appropriate discourse, emerging voice and identity, re-assessed the proposal focusing on these aspects of academic research writing.

The reviewer found that the students on the whole, were writing with competence but highlighted three issues: writing was too descriptive with students writing expository texts rather than as essayist text (see Lillis, 2001) with strong argument; the research proposal template was seen as restrictive, curtailing the students' creative writing ability; and finally, coherent motivation for conducting the research and for research choices was not clearly articulated. The reviewer, in his individual assessments (see Dowse in press) identified some students who were at the stage of developing identity and therefore their voice, while some had not as yet reached this stage.

#### 4. Discussion on findings

The needs analysis in Phase 1<sup>5</sup> revealed that the majority of students entering this particular graduate programme in education were unique in that they were practising teachers, more mature than the average student and perhaps had had a gap in studies at higher education level. In addition, most students had come through the education system situated in a former political era where education delivery for blacks was not the same as that for white students. All students in this cohort were seen as being underprepared for a variety of reasons: underpreparedness due to largely educational background (primarily black students), language background and education (affecting all English Second Language students) and change in discipline (mainly one student) and field of study.

This finding concurred with South African literature, as well as literature from the United States and the United Kingdom where foreign students entering graduate programmes, were seen as being underprepared for study at this level in terms of language proficiency as well as academic literacy competence which includes academic writing proficiency. The results of TALPS and the application and initial proposal assessments, assisted in highlighting the need for some sort of support and developmental programme for students entering the programme.

Initially, the intervention required an academic writing framework for guiding the *process* of developing the *product* (the research proposal) (see Dowse in press). Within the *process* of writing, components of academic writing such as *purpose* (taking note of *register* and *tone*) and the *politics* of writing (considering *genre*, *structure*, *discourse* and *argument*) were further developed within the intervention in an attempt to foster competent academic research writers who were equipped with the necessary academic literacies to move into the next stage of their research. However, the experience in this study is that the timing, frequency, intensity and chronology of the acquisition and development of these components of academic research writing vary according to each participant.

Taking what constitutes academic research writing at graduate level<sup>6</sup> into account, the study was informed theoretically. A specialized programme in the form of a structured academic research writing intervention<sup>7</sup> operating within New Literacies Studies was considered most appropriate. The approach taken in the teaching of academic research writing was underpinned by Lea and Street models and Ivanič's framework. In addition, a genre approach (Hyland, 2003, 2007, 2008; Swales, 1993), which focused on the specialized type of writing needed at graduate level for the writing of the research proposal, formed the core to support the students in the development of their academic research writing proficiency; however, the teaching of academic research writing also moved along the continuum of Ivanič's framework, depending on the need. Aligned with this, are the requirements at graduate level within the South African context (see Higher Education Framework) as well as the faculty and departmental requirements, all aspects to consider when developing such a programme, particularly focusing on relevance and consistency of the intervention.

An issue which arose in the literature is that the students, even though they have shortcomings, should not be viewed through a deficit model but that the intervention should support them by being developmental as well as incremental. Thus, the intervention considered its appropriateness and practicality<sup>8</sup> in terms of delivery and development with the needs analysis showing that students did not just need to develop academic research writing proficiency,

<sup>5</sup>RQ 1: What constitutes academic research writing required at graduate level?

<sup>6</sup>RQ2: What is the level of academic research writing of students entering graduate study?

<sup>7</sup>RQ3: How can graduate students be assisted in the promotion of academic research writing?

<sup>8</sup>RQ4: How appropriate is the intervention in developing academic research writing?



but that other aspects such as discipline-specific content knowledge and research methodology knowledge had to be incorporated and included in the intervention.

The majority of the students gave a good overall evaluation for the programme seminars as well as the contact sessions in contrast to the faculty seminars which tended to be generic and of less value. Students found that the programme seminars were at a suitably high level, related to their research and that the content assisted them in developing new knowledge as well as in understanding the next steps to be taken in their research. In reflection, the supervision team were very aware of the fine balancing act needed to support the students in all three areas throughout the process. However, expert reviewers both felt that more emphasis was placed on these two aspects - discipline-specific content knowledge and research methodology knowledge - compromising opportunities for academic research writing development. Suggestions were given by the expert reviewers on how the focus of the programme seminars and contact sessions could shift with writing becoming the focus with the discipline-specific content and research methodology knowledge being the vehicle through which the development and promotion of academic research writing is effected. However, within this part-time master's programme, although students attended contact sessions regularly during the year-long intervention, some were hesitant about committing to spending more time in working at developing their academic writing proficiency, preferring to spend the time on the writing of their chapters in an effort to complete the dissertation within the set timeframe, thus focusing on the product rather than the process.

In the final evaluative phase of the intervention<sup>9</sup>, Phase 3, it was expected that the students would be successful in completing the writing of their research proposals and that they would successfully defend these, as confirmed by the research proposal defence and the assessment of the final proposals. Thus *expected effectiveness* of the intervention was achieved in that the academic research writing was of a high enough standard for submitting and defending the research proposal. However, even though the students were allowed entry into the second phase of their research, that of conducting their research and writing their chapters, the *actual effectiveness* of the intervention was in question, that is, whether the students' academic research writing proficiency and academic literacies competency was at a high enough level to carry them forward confidently into the next phase. Some improvement was seen in the development of the individual students' academic literacy with the results of the TALPS re-test. Re-assessment of the final proposals was undertaken to generate a profile of academic research writing for each student (see Dowse in press).

Finally, even though the last data is still being analysed, and therefore final conclusions cannot be drawn, the overarching research question of *What are the characteristics of an intervention for promoting academic research writing which will best support master's students in education in the proposal stage of their research?* can offer some characteristics, in conjunction with those mentioned earlier, which appear to be emerging:

In working with graduate students who are full-time teachers and part-time students, the research has shown that an appropriate *learning space* which offers students not only the *physical space*, equipped with relevant IT equipment and resources, but also the *collegial, collaborative and pedagogical space* to interact and learn with and from peers and become part of a community, is vital. Often graduate students feel alienated, isolated and alone, therefore a *community of practice* offers students the support at varying times through their studies and promotes opportunities for interaction, discussion and debate. To take the notion of access a step further, access for students should not just be an initial access to higher education,

<sup>9</sup>RQ5: How effective is the academic research writing intervention in supporting graduates in Education?

but should incorporate access to knowledge, access to discourse, and access to the academy and thus scholarship.

With the master's degree for this particular programme only being offered by dissertation, a *structured programme* which is developmental as well as incremental is needed. It is recommended that the programme incorporate the acquisition and development of *academic writing, discipline-specific content knowledge and research methodology knowledge* to ensure that students are given a solid foundation in these key areas. Such a programme should be designed to meet the needs of students and support them not only through the process of writing their research proposals but continue through the duration of their studies. However, this support, it is advised by the expert reviewers, should continue through to the students' final year.

Research has suggested that because choosing an advisor or supervisor can be a difficult one, a dissertation committee which would comprise a mentor an expert in the field, a coach, an editor, someone to advise on the reading and writing (Bolker, 1998) or a supervision team (Cryer, 2006), could be more beneficial. For the implementation of this intervention, a research triad was created which offered *continuous support and supervision* for the student and in addition, provided an opportunity for the experienced supervisor to offer *supervision mentoring* for the novice supervisors who made up the supervision team. On-going professional development is needed for both novice and experienced supervisors and working within a triad or a group could offer that capacity-development needed both in terms of modelling practice, skills development and mentored experience.

The concern that persisted throughout the implementation of the intervention related to the type of student entering graduate studies in education and the difficulty that many have in completing their studies in a full research dissertation. Thus, this research reinforces the fact that an intervention to support students both with their academic research writing, their discipline-specific content knowledge and their research methodology knowledge is vital, to ensure that firstly, throughput required by the institution is achieved and secondly, and most importantly, taking into account the state of schooling in South Africa, that competent and qualified practitioners in their particular fields, are equipped to take on a transformative role in education by successfully becoming change agents.

### **Key source**

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## Curriculum Development in the Floriculture Sector in Uganda: A Design-based Validation-Research Study

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# 41. Curriculum development in the floriculture sector in Uganda: A design-based validation-research study<sup>1</sup>

Martin Mulder & David Kwagalakwe Kintu

## Abstract

*This chapter describes an Educational Design Research (EDR) project on curriculum development in agriculture aimed at analysing the impact and efficacy of competence-based educational design principles in floriculture education in Uganda. The purpose of this study is to generate a better understanding of these principles. The competence-based education design philosophy was chosen because of the necessity to firmly align the content of the curricula that needed to be developed for senior secondary agricultural-vocational and higher agricultural education with the national, regional and international developments in the floriculture production chain. An asset of competence-based education is the strong relationship between the demands in the labour market and the design of the educational program. In previous studies, principles of competence-based education have been proposed, elaborated and further explored in vocational education and higher education. In various stages of the research process, the principles of competence-based education emerged from practice and theory. In the study reported in this chapter, curricula for two educational institutions were developed and implemented. The validity of the design principles and the effectiveness of the educational program were evaluated by various stakeholders, including graduates and their employers. Based on the employment and evaluation data, it can be concluded that the project has been successful, although there are concerns about the sustainability of the practical component, especially the field attachments of the program. The competence-based design principles were working as intended. Further research is necessary to identify the efficacy and impact of the design principles independently.*

## 1. Introduction to the problem

Professional and vocational education need to be well-aligned to the needs of the labour market and society at large. The competence-based education philosophy (Mulder, 2011; in press) addresses this issue and tries to establish insights as to how to design curricula that meet these needs (Mulder, 2012a; 2012b). The approach is applied in many professional fields, like in medicine (Frank, Jabbour, Fréchette, Marks, Valk, & Bourgeois, 2005), purchasing (Mulder, Wesselink, & Bruijstens, 2005), extension (Karbasioun, Mulder, & Biemans, 2007) and agriculture and rural development (Pant, 2012). A matrix of principles and implementation levels of competence-based education was constructed which is based on an extensive literature review and expert consultations (Wesselink, 2010; see Box 1). This matrix is being validated in Dutch vocational education, but wider validation of the efficacy of the competence-based education design principles is necessary. Furthermore it is important to evaluate the outcomes of a competence-based curriculum. A problem in vocational and higher education is that the

<sup>1</sup> The project on which this chapter is based was funded by the Netherlands University Foundation for International Cooperation (NUFFIC).

alignment of many education programs with the needs of the labour market is limited or even non-existent.

Regarding the notion of competence-based education, we would like to point at the fact that the competence-movement started in the USA in the fifties of the last century with publications of White (1959), McClelland (1973), Gilbert (1978), Boyatzis (1982), Spencer and Spencer (1993) and many others. Grant, Elbow, Ewens, Gamson, Kohli, Neumann, Olesen, & Riesman (1979) reviewed a series of the early competence-based attempts to align higher education to the labour market. The competence-based education movement of this period were heavily criticized because of their behaviouristic nature (Mulder, Weigel, & Collins, 2007). In a later stage competence theorists pointed at the necessity to stress the interpretative (Sandberg, 2000), holistic (Velde, 1999) and comprehensive (Wesselink, 2010) nature of competence. These notions of competence are more related to integrated occupationalism and situated professionalism (Mulder, 2014) and object against the reductionist behaviouristic nature of the early competence-based education programmes. In the matrix of competence-based education, these considerations have been taken into account.

The validation of the principles of competence-based education took place in a curriculum development project in the field of floriculture (flower-growing, mainly roses and chrysanthemums) with two educational institutions and the flower production and export association in Uganda. In Uganda, like many in the South, the agricultural sector dominates the economy. Currently, agriculture employs 80% of the workforce in Uganda. Commercial floriculture in Uganda started in the early 1990s and employs around 6,000 persons. The number of people supported directly and indirectly by floriculture is around 30,000 persons. Good training and education provision in the field of horticulture was lacking, whereas Oyelaran-Oyeyinka and Sampath (2007) attributed fluctuations in Uganda's performance among others to education and training issues. The lack of up-to-date education programs in agriculture is not unique for Uganda. Comparable projects were and are being conducted in Ethiopia, Indonesia, and Kenya. The lack of a dedicated and current education program in the field of floriculture (CBFU, 2010) was the main reason for starting a capacity building project in that field in Uganda, which started in 2006 and ended in 2010.

Within this sector, three main stakeholders were identified: the flower farms, research institutes and education and training institutes. Together, these stakeholders were expected to cooperate in the development of various ways to develop competence in the sector: learning on the job programs, knowledge exchange between flower farms and research institutes, knowledge exchange between research institutes and education or training organisations, and activities for knowledge construction in action (see Figure 1).

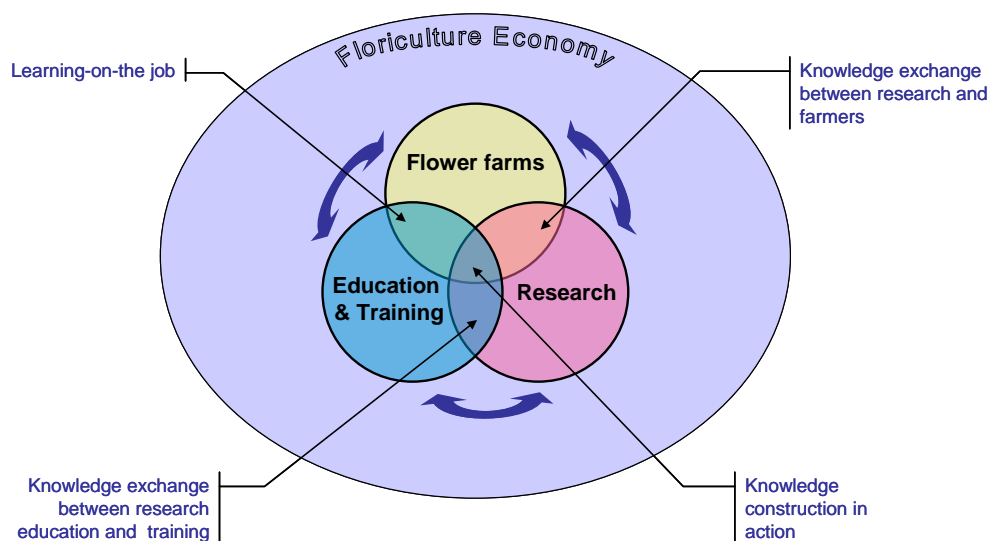


Figure 1: Cooperative learning activities at intersections of stakeholders

The interest in the capacity development project was to initiate and facilitate knowledge construction in action between the three parties involved: farms, the Ugandan Flower Export Association (UFEA), Bukalasa Agricultural College (BAC) and Mountain of the Moon University (MMU) and education and research institutes from the Netherlands (Wageningen University (WU), Agricultural Economic Institute (LEI), Practical Training Centre (PTC+), Applied Plant Research (PPO)).

The curriculum development was embedded in a larger project. The other components of the project (see Figure 2) were capacity building, applied research, investments and smallholder floriculture. Capacity development was aimed at developing course guides and materials together with and for the lecturers, who, as said, got training for their new role.

For all parts of the project, there were four development phases: (1) Needs assessment, (2) Design, (3) Implementation and (4) Evaluation.

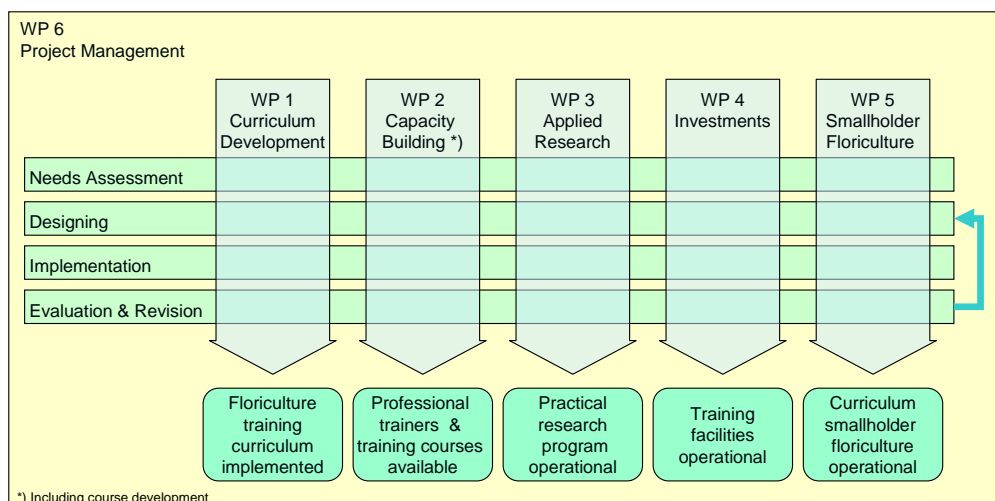


Figure 2: Phases in the floriculture capacity development project (WP=Working Package)

The curriculum that was developed was defined at Diploma level. The Diploma programme was designated for training future managers and aimed at registering A-level graduates with low grades who did not qualify for a degree (Bachelor) programme. The duration of the programme was decided to be two years. The idea was to also develop a one-year Certificate programme, and short tailor-made courses with a modular character. The research reported in this chapter is based upon the development of the Diploma program.

In the next sections of this chapter we will elaborate the education design problem and research questions, the validation research design, the design research methods and data collection, the context of the curriculum development project in context, the implementation of the principles of competence-based education in the case, the results, the validation of the principles for competence-based education, and the lessons learned.

## **2. Education design problem and research questions**

As stated, this chapter describes an EDR project on curriculum development in the field of floriculture in Uganda and analyses the underlying competence-based educational design principles to generate a better understanding of these principles. The curricula were developed because of the need for floriculture education felt in the sector of flower production and export. Many flower farms were and still are depending on expatriates, especially from Europe, Kenya and India for managerial and supervisory jobs. The standard and volume of floriculture education in these regions and countries is higher. Therefore the floriculture sector in Uganda decided to apply for a NUFFIC capacity development project, which was granted in an open competition.

From a curriculum research perspective this case of capacity development provided a good context to experiment with a specific curriculum development approach, which is based on competence theory. As stated, the competence-based education design philosophy was chosen because of the necessity to firmly align the content of the curricula that needed to be developed for senior secondary agricultural-vocational and higher agricultural education with the national, regional and international developments in the floriculture production chain. This production chain is characterized by high competition, quality, technology and international scope. As with most floriculture produce, export is oriented towards the large auctions and retailers in Western-European countries. A strong asset of competence-based education is the strong relationship between the demands in the labour market and the design of the educational program, which is the main reason as to why this approach was employed in this case. In previous studies, principles of competence-based education have been proposed (Mulder, 2004). Wesselink (2010) elaborated this and constructed a so-called matrix of competence-based education. This matrix consists of 8 principles of competence-based education with four implementation levels, ranging from no to maximum implementation of those principles. Teacher teams can use this matrix to portray where their program is in terms of the implementation of the principles of competence-based education (Wesselink, Dekker-Groen, Biemans, & Mulder, 2010). We call this the actual 'competentiveness' of the curriculum. They can also define the development policy regarding the curriculum. In this way teacher teams can use the matrix as an articulation instrument. It appears that using the matrix in teacher teams evokes constructive communication about the present and desired level of competentiveness of the curriculum. Currently, the matrix is further evaluated in vocational education (Sturing, Biemans, Mulder, & De Bruijn, 2011). It has also been studied in higher education in Indonesia (Nederstigt & Mulder, 2011).

So the purpose of this chapter is twofold.

1. To describe the curriculum development project on floriculture in Uganda and to assess its impact on graduate employment.
2. To further test the validity of the design-principles of competence-based education in this curriculum development project.

This leads to the following research questions:

1. What was the impact of the new education programs in floriculture on graduate employment?
2. What was the efficacy of the principles of competence-based education in the design process of the competence-based floriculture curriculum?
  - a. How did the curriculum developers use the eight principles of competence-based education?
  - b. What challenges were encountered in using the principles of competence-based education as a guide for curriculum design and development in Uganda?
  - c. What adaptations are needed in the principles of competence-based education based on this validation study?

### 3. Research design

According to the work of Nieveen, McKenney and Van den Akker (2006) and Plomp (2009) this chapter can be seen as an example of a *validation study* with elements of effectiveness research. It is still a validation at small scale, or a so-called beta-trial, which means that the research is conducted in a carefully chosen site and that support is given, which will be elaborated below. The research is problem-driven, the problem being the disconnection between the curriculum (as in many Southern educational programs) and the needs for national and regional socio-economic development. The research has gone through several stages. In the first stages of the research the emphasis was on the development of curricula based on principles of competence-based education, whereas in the current stages principles of competence-based education are being tested in a series of curriculum development projects which serve as case studies to validate the educational design knowledge accumulated.

The design research project in this case consists of the following phases:

- Preliminary research  
In this phase the context of the curriculum design process was analysed. It also included a phase of labour market, job and competence analysis. In this phase the principles of competence-based education were already applied, by developing a competence profile of graduates of the horticulture education programmes.
- Curriculum design  
In this phase the components of the curriculum were drafted. These were defined by course titles, learning outcomes and first specification of the course content and assessment strategies. Again, in this phase, principles of competence-based education were used, for instance the identification of core occupational problems, the specification of competence assessment strategies, the identification of authentic learning situation (amongst which internships or field attachments), the integration of knowledge, skills and attitudes, and the gradual development of self-regulated learning. During accompanying teacher professional development, emphasis was put on the coaching role of the lecturers, and the development of a life-long learning attitude.
- Curriculum development  
In this phase the components of the curriculum were further specified. Also during this phase the design principles were applied and further deepened.



- **Assessment stage**  
In this phase the impact of the curriculum and the use of the competence-based education design principles were assessed. This was done in a participatory way. The researchers were part of the curriculum design project. During the assessment stage the educational design principles were validated. Furthermore, adaptations of these principles were identified for future use of the principles in other contexts.

The use of the principles of competence-based education design will be elaborated below. Although Nieveen et al limit validation research to the advancement of *instructional theory*, we believe that validation research is equally important in the field of *curriculum theory*. We believe that curriculum design principles emerge from deliberate attempts to use certain design guidelines in consecutive cases studies. It is the continuous reflection on the experiences with implementing the guidelines that shapes the confidence in the efficacy of these guidelines over time. In sum, what Nieveen et al suggested was exactly done: to develop and implement specific learning trajectories to test the theoretical basis of the design.

#### **4. Design research methods and data collection**

The research method used to answer the first research question (on program impact) consisted of interviews with the 30 stakeholders in the educational program: lecturers from the respective education institutes, managers and supervisors from twelve flower farms in Uganda and graduates. The interviews were structured according to certain main questions for each stakeholder group (see below). The stakeholders were selected based on their involvement in the curriculum project and access. Access was especially an issue for interviews with employers and graduates as they are in remote areas which are not easily accessible. Furthermore, making appointments via email or mobile phone is in most cases not possible, so site visits are needed to make appointments. Making these site visits may take a full day. Furthermore, when appointments for interviews are made, it is still not always sure that the interviews will go on. This means that data collection in the field is extremely time-consuming. Arriving at a response group of 30 persons is therefore quite satisfying.

The interviews were aimed at tracing the work places of the graduates, views of lecturers on the impact of the program, perceptions of employers of regarding the quality of graduates, and experiences with and view of graduates the program and their employment situation. Data of lecturers, employers and graduates were collected within the first year after graduation of the first batch of students.

To answer these questions, data were collected about the perceptions of the various stakeholders with the training programs and the labour market entry of the graduates. At the time of the assessment, only one group of students had graduated. Data was analysed using descriptive quantitative and qualitative analysis techniques. The following categories of questions were asked to the different stakeholders in this evaluation (Kintu, 2010). See Gulikers, Biemans and Mulder (2009) for a comparable multi-stakeholder evaluation of competence-based education):

- Graduates were asked a series of questions, aimed at their current job, their satisfaction with the education program, competencies they did develop during the programme, aspects of the program that had most impact, and the activities they did after they finished the study program.
- Employers (general managers or owners) were asked fourteen questions, including questions as to whether the graduates were properly prepared to work at their flower farm and whether they could smoothly start working.

- Internship supervisors were partly asked the same questions as the employers. Other questions for them included their satisfaction with the students and graduates.
- Interns were asked fourteen questions, including questions about their satisfaction with the internship.
- Lecturers were asked twenty-one questions, amongst which questions about their satisfaction with the program, and their perception of the effects the programme had on students.

The research method used to answer the second research question (about the efficacy of principles of competence-based education) also consisted of participatory interviews with the curriculum developers and lecturers. Special attention was given to the way in which the curriculum developers used the principles of competence-based education and challenges which were encountered in using these principles.

Prior to the job and competence analysis, a training on floriculture and competence-based course development was provided for the nine selected lectures at Practical Training Centre (PTC+) in Ede, the Netherlands, for a period of 2 months. Six persons of this group were lecturers from the respective education institutes in Uganda, and three were trainers from the flower industry. They were equipped with principles of competence-based education and floricultural skills for developing and implementing a competence-based curriculum. The lecturers and trainers defined and helped in selecting the courses to be taught as well as the training materials to be used during the learning trajectory. They were involved in the design of the training and greenhouse facilities that were constructed at the university and college. On their return, these nine persons together with their colleagues and project-partners from the Netherlands designed and developed the curriculum, teaching guides and hand-outs for all the modules to be taught.

The principles of competence-based education used were represented in the matrix for competence-based education (after Wesselink, 2010).

*Table 1: Principles of competence-based education*

1	The competencies, that are the basis for the curriculum, are defined
2	Core occupational problems are the organizing unit for (re)designing the curriculum (learning and assessment)
3	Competence development of students is assessed before, during and after the learning process
4	Learning activities take place in different authentic situations
5	In learning and assessment processes, knowledge, skills and attitudes are integrated
6	Self-responsibility and (self)-reflection of students are stimulated
7	Teachers both in school and practice fulfil their roles as coach and expert equally
8	A basis for a lifelong learning attitude for students is realized

These principles were divided in four levels of implementation: (1) Not; (2) Starting; (3) Partially, and (4) Completely competence-based. The meaning of the principles at the various levels was semantically specified, based on examples like the model for quality improvement of the European Foundation for Quality Management. See for the complete model Box 1.

## 5. Description of the curriculum development project in context

In this section the curriculum development project will be described which is necessary to understand the context of the research.

The curriculum development activities were divided in a series of steps.

- a. The core curriculum development staff were trained in and exposed to the floriculture sector and principles of competence-based education development in the Netherlands.
- b. Informal curriculum evaluation with key players of the floriculture program to evaluate the present programs and materials (there were hardly any).
- c. Identification of stakeholders (Mulder, 2006), such as producers, farm owners, the UFEA, research institutes, universities, governmental bodies and non-governmental organisations (NGOs).
- d. Needs assessment with various representatives of the stakeholders by site visits and interviews. This was the actual *needs assessment* phase. Essentially, an inventory of future tasks and competencies was made of the graduates of the Diploma and Certificate program. This led to the identification of representative *job roles* with *occupational profiles* and the specification of *job tasks* with *competence lists*.
- e. A concise labour market analysis was incorporated in this study (which turned out to be quite complicated as many farms and governmental bodies do not want to disclose that kind of information for various reasons, or they simply did not have that information; visiting farms appeared to be extremely labour-intensive because of the lack of reliable telecommunications and large distances to remote places).
- f. Literature analysis to see what is going on in the field of horticulture training and development and the floriculture sector.
- g. Courses developing by completing course formats. The process was an iterative and collaborative process between the teaching staff of and consulting experts, all bringing in their own expertise. During this process a deliberative approach was followed.
- h. Program implementation. In both education institutes, the BAC and MMU, the curriculum was implemented, based on teaching guides and teacher materials developed under the supervision of PTC+.
- i. Lastly, continuous interactive alignment with stakeholder needs and preferences was implemented.

Step g: course development, took most of the time during the whole development process. Based on the competence descriptions curriculum components were formulated and described. This was the basis of a tentative list of course titles and a table of credits per course, including various specifications as to the amount of time dedicated to theoretical and practical learning and assignment and sequencing of courses within the various study years and semesters. During this process various drafts emerged on which advice was solicited from the project partners, and based on that successive insights and suggestions were taken on board. Finally the process resulted in the curriculum which was elaborated and later implemented. During the whole process of needs assessment, curriculum design and development, and the implementation, the principles of competence-based education played a guiding role in decision making. How this worked will be described in the next section.

## 6. The principles of competence-based education

The competence-based education principles which were tested in the floriculture curriculum development project are presented in Table 2.

Table 2: Principles of competence-base education (after Wesselink, 2010)

	Principle	Not competence-based	Starting to be competence-based	Partially competence-based	Completely competence-based
1	The Job Competence Profile (JCP) that is the basis for the study programme is defined.	There is no JCP.	There is a JCP, but it was constructed without input from the professional practice. This JCP was used during the (re)design of the study programme.	A JCP was constructed with input from the professional practice and this profile is fixed for a longer period of time. The JCP was used during the (re)design of the study programme.	A JCP was constructed with input from the professional practice and this profile is synchronised frequently with the regional and local professional practice including the major trends. This JCP was used during the (re)design of the study programme.
2	Core Occupational Problems (COPs) are the organising unit for (re)designing the study programme (learning and assessment).	There are no Core Occupational Problems specified.	COPs are specified and used as examples in the (re)design of the study programme.	COPs are specified and are the basis for the (re)design of some parts of the study programme.	COPs are specified and these are leading factors in the (re)design of the whole study programme.
3	Competence development of students is assessed before, during and after the learning process.	Assessment is the final stage of a learning process and takes place at a fixed moment.	Assessment takes place at several moments, is used for formal assessment and does not play any role in the learning process of students.	Assessment takes place before, during and after the learning process and is used for both formal assessment and competence development of students.	Assessment takes place before, during and after the learning process and is used both for formal assessment and competence development of students. Students determine the moment and format of assessment themselves.

Table 2: Principles of competence-base education (after Wesselink, 2010) (continued)

	Principle	Not competence-based	Starting to be competence-based	Partially competence-based	Completely competence-based
4	Learning activities take place in different authentic situations.	Learning in practice is of subordinate importance and there is no relation with learning in school.	Learning in school is leading. Sometimes, by means of cases a link is made to learning in practice or experiences from practice.	Learning activities take place to a large extent in authentic settings, but the relationship with learning in school is insufficient.	Learning activities take place to a large extent in a diversity of authentic settings and are clearly related with the learning activities in practice.
5	Knowledge, skills and attitudes are integrated in learning and assessment processes.	Knowledge, skills and attitudes (K, S and A) are separately developed and assessed.	K, S and A are sometimes integrated in the learning process. K, S and A are assessed separately.	K, S and A are integrated in the learning process or in the assessment procedure.	Integration of K, S and A is the starting point for both learning and assessment processes and therefore operationalised.
6	Students are stimulated to take responsibility for and reflect on their own learning.	Learning activities are characterised by external steering: students carry out assignments by means of elaborated instructions. There is no self-reflection.	In a limited part of the learning activities, students determine for themselves the way they learn. There is hardly any reflection on the learning process and functioning in vocational settings.	Students themselves determine the way they learn, and the time and place of learning, based on reflection on the learning process and functioning in vocational settings.	Students are after all responsible for their own learning processes based on their learning needs.
7	Teachers both in school and practice fulfil their role as both coaches and experts.	Knowledge transfer is central to the learning process.	To a limited extent the responsibility for the learning processes is handed to the students. Teachers support through guidance.	Students enjoy a certain level of autonomy in determining their own ways of learning. Teachers observe when students need support and offer it.	Teachers stimulate students to formulate learning needs and based on self-reflection to determine their own learning processes.

Table 2: Principles of competence-base education (after Wesselink, 2010) (continued)

	Principle	Not competence-based	Starting to be competence-based	Partially competence-based	Completely competence-based
8	A basis for a lifelong learning attitude for students is realised.	In the study programme no attention is paid to competencies that are related to learning or (labour) identity development.	In the study programme attention is paid to competencies that are related to learning and (labour) identity development, but these competencies are not integrated in the learning process.	In the study programme competencies related to learning and (labour) identity development are clearly related to vocational core problems and attention is paid to those competencies to a large extent.	In the study programme competencies related to learning and (labour) identity development are integrated and reflection on the future career of students takes place.

These principles were used in the training of staff and the support of the curriculum development process.

## 7. Results

In this section the results of the study will be presented. This will be done in the order of the research questions. First, the results regarding the study program impact will be presented, and next the results regarding the validation of the competence-based design rules. In actual practice program implementation and impact are strongly related. We address the impact issue first because we believe that, from a validation perspective, this issue precedes the implementation, although in time the implementation process precedes the impact of the study program.

### Study program impact

Regarding the impact of the study program on the employment outlook of graduates, the first signs were positive. Thirteen out of fifteen of the graduates from the first graduate generation were working in the flower sector. One graduate was employed by the college itself, and two were dealing in agricultural products and independent entrepreneurs. One graduate was enrolled in further studies. The main conclusion of this study therefore was that the impact of this two-year Diploma course had significant impact in the floriculture sector, as it enabled practically all students to find a job in the sector, and the sector retained the vast majority of these graduates.

However, a meeting was held with a small delegation of the group of graduates. This meeting showed that the graduates were very dissatisfied with the labour conditions in the farms in which they were working. It appeared that the salaries paid by the farms were very different, and in general very low, considering the graduates had a Diploma-level qualification. Some farms paid a monthly salary of as little as 80,000 Uganda shillings per month for the graduates (100,000 Ushs = US\$ 41.49; 14-03-2011). Regarding their career development, graduates feared that they would have to wait several years (5-7) before they would be promoted to a higher job level with significantly more income. This picture was confirmed during on-site in-depth interviews with graduates, supervisors and managers.

### **Validation of the competence-based design rules**

Regarding the educational design results, the competence-based education philosophy was appreciated by the various stakeholders. Especially the practical nature of the curriculum was applauded. Based on these observations (which were confirmed during participatory design and implementation processes), it was concluded that the application of the competence-based design rules had a positive effect on the total curriculum quality.

Though many of the stakeholders involved in the designing, development, implementation and assessment of the curriculum felt that it required a lot of time and effort to design and maintain its functionality. This was partly due to the difficulty in coordinating the large number of stakeholders involved who were located in different areas of the country as well as the reluctance of stakeholders to re-assess and re-design the curriculum periodically. In education development cooperation this can only be stimulated by extensions of projects, as ownership of education programs which are trade related and go along with process of deep educational change is not easily transferable, although the official philosophy behind these projects is that Southern stakeholders already are the owners of the educational programs. Inasmuch as the general consensus applauded the practicability of the curriculum, the sustainability remained questionable. This is also a matter of resources, as internships are costly for the participants and in this case not included in the fees.

As stated, teaching staff interviews included questions about the perceptions of and experiences with the eight design principles. The responses of these questions were aggregated, and summarized below.

*1. The competencies, that are the basis for the curriculum are defined.*

The job profile was instrumental for defining the content of the curriculum. Curriculum components could be linked to job tasks and competencies. The flower farms clearly defined the job profiles, tasks and competences needed for the two education institutes (BAC and MMU) involved in the project.

*2. Vocational core problems are the organizing unit for (re)designing the curriculum (learning and assessment).*

The intention was to use COPs as the organizing unit for (re)designing the curriculum. The final curriculum, however, is still predominantly based on science fields, although there are ample practical training moments, including internships. It appeared that thinking in traditional subjects appeared to be strong. MMU was more flexible and willing to adopt new approaches in (re)designing of the curriculum as compared to BAC, because it was a young institution and privately managed. On the other hand, BAC that was older and publicly managed had to adhere to government regulations. At the end, MMU that was at University status was given the responsibility of coordinating the design and development of the curriculum.

*3. Competence development of students is assessed before, during and after the learning process.*

This is accomplished by continuous formative assessment. Assessment methods that were used were case studies, presentations, reports, oral exams and written exams. Authentic assessment appeared to be new and challenging. This principle however resulted in specifications of the assessment methods in the curriculum units. Both MMU and BAC set and moderated their own assessments because of the time difference at assessment, but the final diploma certificates were issued by the university because of its higher status.

4. *Learning activities take place in different authentic situations.*

This principle resulted in inclusion of greenhouse practice, practical sessions in the classroom and workplace learning in different flower farms. There were 3 internships in the curriculum. The 1<sup>st</sup> internship lasted 2 weeks and was an orientation for students. The 2<sup>nd</sup> internship lasted 1 month, and students specialized in 2 departments. The 3<sup>rd</sup> internship lasted 2 months and was a kind of research that should be carried out at a flower farm. The sustainability of the internships seemed to be a challenge.

5. *In learning and assessment processes, knowledge, skills and attitudes are integrated.*

A deliberate attempt was made to integrate knowledge, skills and attitudes in the curriculum. In various courses this resulted in more attention to practical skills and attitudes than usually was the case. Traditional exams are still prevalent, however, also because of national exam regulations.

6. *Self-responsibility and (self)-reflection of students are stimulated.*

At the university this was emphasised more than at the college, due to the fact that the college was part of secondary education, and thus bound to the rules and regulations regarding of the Ministry of Education and Sports. Gradual augmentation of self-regulation was promoted throughout the curriculum as a result of this principle. At the College students were working independently in the greenhouses.

7. *Teachers both in school and practice fulfil their roles as coach and expert equally*

This principle has not fully been realized. Teachers are basically not coaching the students, also because there are only very limited educational materials to enable independent and collaborative learning. At the flower farms supervisors are not always aware of what the students need to be doing at their farm.

8. *A basis for a lifelong learning attitude for students is realized*

During the training of lecturers and trainers, they were made aware of continuous learning lines in floriculture, from initial education to continuing vocational training or human resource development. Due to the limited contacts lecturers have with flower farms, the implementation of this principle is quite difficult.

The principles are conceived as guidelines for good practice, but in reality they imply educational innovation and change, which is resisted in general because of various reasons such as repressive regulations regarding education by the state and institution, the mandatory national curriculum, administrative teacher control and lack of development resources. In the college with which we cooperated there was basically no local human resource management and there were almost no facilities for human resource development. Grants to teachers to participate in further education (abroad) were regulated by the Ministry of Education and Sports on an individual basis.

In a comparable horticulture curriculum development project in Ethiopia (Mulder and Gulikers, 2011), in which the same educational design principles were used, the experiences are highly similar, and it is expected that in a project running in Kenya, again with the same design principles, the same processes will occur (Mulder, 2012a; 2012b). Efforts will be made to accommodate the principles to the local situation.



The results of this design-based curriculum research study show the mixed experiences with using the principles of competence-based education in practice in the South. The results need to be taken into account when using these principles in next projects. Apart from that, we maintain the conclusion that implementing (part of) the set of principles (even to a limited extent), has a positive effect on the impact of education programs in higher agricultural education. The curricula are better aligned to labour market developments and needs, and as a consequence, students are likely to have a better labour market perspective. However, various amendments are suggested for using the principles of competence-based education in a wider perspective. These will be addressed in the following section.

## 8. Lessons learned

Having answered the main research question, regarding the impact of the floriculture education programs on graduate employment, which was found to be positive, and the validation of the design principles of competence-based education, which appeared to be instrumental in the development of the curricula, it was also clear that the use of the principles of competence-based education was not without challenges. The most important findings have been reported above, under the list of principles. The last (specific) question was what adaptations were needed in the principles of competence-based education based on this validation study. These adaptations are important when the set of principles are being used in other (culturally varying) contexts. In Table 3 the adaptations are being addresses by principle.

*Table 3: Amendments on the principles of competence-based education*

1	<p><b>The competencies, that are the basis for the curriculum, are defined</b></p> <p>A suggestion for amendment of this principle is to speak about the Job Competence Profile (JCP) and indicated in Table 2. Working with a competence profile, model or framework goes further than just presenting a list of competencies which are relevant for the curriculum. Having a profile has the advantage that it also can co-structure the curriculum. Furthermore, in this case (and similar previous cases) it appeared to be necessary to stratify the job. This is important to determine whether specialisation in the educational program is needed, or that a common program will suffice.</p>
2	<p><b>Core occupational problems are the organizing unit for (re)designing the curriculum (learning and assessment)</b></p> <p>Suggestions for amendment of this principle are:</p> <ul style="list-style-type: none"> <li>• To speak about occupational problems as these are more general than vocational problems, and to explain the nature of the problems, being core problems in occupational practice; persuasive examples of problems which are used to define programme components may help to understand the power of this approach.</li> <li>• The problem-based nature of the competence-based curriculum conflicts with mono-disciplinary interests and perspective of lecturers. Special attention needs to be given to the importance of interdisciplinary education and the extent to which mono-disciplinary introductions to given science fields is necessary. The competence profile resulting from labour market and competence analysis should be used to guarantee that all disciplines which are relevant for the occupational profile get a fair share in the curriculum. It is the tasks of curriculum management to warrant this.</li> <li>• The issue of authentic assessment (next principle) should be related to the occupational reality. This needs stronger emphasis.</li> </ul>

Table 3: Amendments on the principles of competence-based education (continued)

3	<p><b>Competence development of students is assessed before, during and after the learning process</b></p> <p>Amendments of this principle which were suggested by the validation are the following:</p> <ul style="list-style-type: none"> <li>• The value of assessment for learning needs to be incorporated in the description of this principle.</li> <li>• Assessment is typically seen as examination of knowledge and skills, whereas competence assessment also includes the component of attitude towards the professional field.</li> <li>• There are many assessment strategies; however, in the specification of the assessment strategy special attention has to be given to the strategic alignment of the learning objectives, the curriculum content, the learning activities and the assessment methods.</li> </ul> <p>The level of competence assessment also has to be taken into account. The pyramid of Miller (1990), in which levels of knowing, knowing-how, showing-how, and doing are distinguished. In competence-based education students have to show their mastery of crucial competencies by authentic task performance.</p>
4	<p><b>Learning activities take place in different authentic situations</b></p> <p>The latter finding needs further reflection in the future, as, if there are no facilities or resources to implement authentic learning e.g. via internships or field attachments, the nature of the competence-based education approach is considerably compromised. Experiencing the reality of the occupational field and practicing and further developing key competencies in an authentic working/learning environment is deemed essential in competence-based education. So if internships etc. are not possible, forms for simulated practice need to be in place, although these also require specific resources such as in this case educational greenhouses, fertigation systems, integrated pest management facilities and plots for field trials.</p>
5	<p><b>In learning and assessment processes, knowledge, skills and attitudes are integrated</b></p> <p>In competence-based education which is preparing for jobs, occupations or professions, knowledge and skills are naturally included, but the integration of professional attitude development is not always obvious. Nevertheless, the professional attitudes of graduates of vocational and professional education are important in selection and placement processes of employers. As stated above, the integration of knowledge, skills and attitudes in learning and assessment is therefore a necessity. The way in which this can be achieved puzzles many educational practitioner however. But when designing competence-based curricula around core occupational problems, the integration of occupational attitudes is self-evident. Addressing attitudinal development in educational practice needs specific attention, and for these, specific learning outcomes can be formulated and assessed. So this principle does not need adjustment; the implementation of this principle however needs clear explanation, supported by examples.</p>

Table 3: Amendments on the principles of competence-based education (continued)

6	<p><b>Self-responsibility and (self)-reflection of students are stimulated</b></p> <p>This principle clearly needs adaptation; in fact it needs adaptation in two ways. Firstly, self-regulation is dependent on the maturity and motivation of students. So in higher grades and education levels, there is more opportunity for and inclination towards self-regulation than in lower grades and levels. Individual differences also need to be taken into account as well. Secondly, culture plays an important role, since in certain cultures it is not common or even not just to have an independent interpretation of reality and plan one's own study career. In those contexts it is highly unlikely that self-responsibility and (self)-reflection are being valued, let alone supported. Nevertheless, if students are being prepared for a competent professional life, a certain degree of self-regulation is necessary.</p>
7	<p><b>Teachers both in school and practice fulfil their roles as coach and expert equally</b></p> <p>The adjustments regarding the previous principle are also pertinent for this and the next principle. These principles imply a certain vision on the professional in society. They are seen here as independent practitioners, who need a certain set of key competencies, and who need continuous further professional development. According to this vision, lecturers should therefore support the development of the future professionals, and guide the learning process of their students. In this sense, lecturers should not only be content-matter experts who explain subject matter to students. They should also value the role of being a coach of the students, who helps them with their learning process. The adjustment here is that this vision needs to be shared; if not, the implementation of these principles is hampered, as well as the competence-based nature of the educational design.</p>
8	<p><b>A basis for a lifelong learning attitude for students is realized</b></p> <p>This principle does not require further adjustment, albeit that it is difficult to realise in a resource-wise challenging educational environment. However, the teaching staff can easily explain to students that getting the diploma does not mean that they will stay competent as graduates. Further development is needed as the world of work is constantly changing, also in the South. Obviously, the inclusion of the development of a life-long learning attitude in educational programs is not easy, and needs special attention. Just mentioning that it is important for the future does not really help in most cases.</p>

In this validation study, in which stakeholder perceptions and labour market effects of design specifications were tested via replication logic, further longitudinal studies are needed. The development of the principles behind the matrix of competence-based education and the subsequent matrix took several years. The research was carried out in various PhD-projects and further validation of the matrix is still going on. Projects in which the matrix is tested serve as case studies. The validation research questions that guide the implementation continually circle around the efficacy of the design principles. By doing that we are building the knowledge base on the main characteristics of competence-based curricula.

During EDR as in the project we described there is ample opportunity to communicate with designers, users, recipients and general stakeholders of programmes in higher education about the meaning of certain principles, levels and further specifications as in the cells of the matrix we used.

An international education development cooperation context of the EDR project we conducted creates new perspectives as well as challenges. It is interesting to see that many educational problems are the same around the globe, but it is equally remarkable how teacher development teams are bound by their educational cultures and systems. In another publication (Mulder and Pachau, 2010) we have elaborated on the challenges of this project, which are about the long road to public approval of curricula in secondary and higher education which is not only caused by bureaucratic red tape, but also by sequencing of project activities, Human Resource Management (or rather: the lack thereof), teacher professional development and the benefits of international exposure to the floriculture sector, the sustainability of internships in relationship with lack of sources for financing transportation, accommodation and living expenses.

Notwithstanding the many hurdles the project had to take, it was very rewarding to see that the graduates of the first group all got employed, although some were dissatisfied with the labour conditions of their job. This indeed is an issue which would need to be solved by the association of flower exporters at sector level, but the question is whether collective labour agreements are feasible in this era of neo-liberalism. However, priority needs to be given to this issue to make the project results sustainable over time, because when the majority of the graduates feel that they did not make the right choice, this will have far-reaching repercussions on the floriculture programmes.

Two further lessons learned have to do with the broad needs assessment phase (including preliminary research, including needs assessment, context analysis, and literature review) in our project and with the cooperation between two different educational institutes. In general (regarding needs assessment), in Western societies experts and representatives from a certain industry can determine the curriculum requirements to a large extent. They are often requested to articulate education and training needs which are then aggregated to job, occupational, professional or competence profiles. However, it can happen that 'experts' do not have access to state-of-the-art information about an international sector as floriculture. It is also possible that the industry does not employ 'ideal' business models. Therefore, information of several stakeholders always needs to be considered against the background of the educational philosophy of the college or university. It is recommendable to find this out during the context analysis or as part of the preliminary research.

Regarding the cooperation of two different educational institutions, certainly when they are of different levels, such as a vocational college and a university, educational design terminology can be confusing. What one would call a module, another would call a course unit, etc. In our project this problem was - partly - solved by proposing standard terminology from educational science and practice, so that both institutions could refer to that. As long as others do not have to work with the concept this works well, but during implementation of the programmes, when lecturers and administrators who were not part of the design team are involved, it gets more difficult. So, also in this project participation in educational design appeared to be essential, although participation has its limits.

Finally we would like to list the specific research methods which are recommended in follow-up research:

1. Qualitative multi-perspective iterative interviews for needs analysis. This has been done by interviewing individual stakeholders from their own perspective, and to use insights in the first interview in the later ones.

2. Stratification of the profession, group interviews for generating and structuring task and competencies lists. This was also done, resulting in the specification of various job profiles.
3. Large scale task performance surveys to triangulate the qualitative data. This was not done in this study because job holders population descriptives were not available, nor are large groups of individuals hard (if not impossible) to reach in rural areas in the case we described.
4. Testing sector-specificity of job profiles. In this case the stratification of the job profiles was sufficient, as it coincided to a large extent with the sectors at stake.
5. Job profile mapping; this was done in this study. For each job there one profile was developed.
6. Job picture development. This was not done in this case as the job and competence profiles were sufficiently clear.
7. Competence mapping. This was also done, resulting in the competence profiles described in this chapter.

Space in this chapter does not allow us to elaborate on that, but interested readers are referred to Mulder, Wesselink and Bruijstens (2005).

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## Design Research Within Undergraduate Mathematics Education: An Example from Introductory Linear Algebra

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## 42. Design research within undergraduate mathematics education: An example from introductory linear algebra

Megan Wawro, Chris Rasmussen, Michelle Zandieh & Christine Larson

### Abstract

*The aim of this chapter is to detail an example of design research in undergraduate mathematics. The results we present is an instructional sequence known as the Magic Carpet Ride (MCR) sequence and the underlying theoretical rationale for the sequence. The example, which fosters students' reinvention of span and linear in/dependence, comes from a sequence of classroom teaching experiments conducted within inquiry-oriented linear algebra classrooms in the Southwestern United States. Within this chapter, we emphasize how the Realistic Mathematics Education heuristic of emergent models and Gravemeijer's (1999) four levels of activity inform the MCR sequence.*

### 1. Introduction

Over the past twenty years, mathematics education research has begun to shift away from an exclusively cognitive focus to one that acknowledges the situated nature of student activity within the classroom and broader communities of practice (e.g., Lave, 1988; Wenger, 1998; Yackel, Rasmussen, & King, 2000). A second shift in the field reflects the tight integration and equal status of theory and practice. The design research approach of classroom teaching experiments (Cobb, 2000), which is central to our work in linear algebra, is especially well suited to both of these shifts in the field.

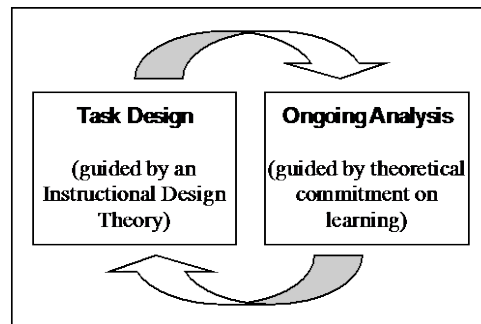


Figure 1: The design research cycle

As illustrated in Figure 1, design research in a classroom teaching experiment consists of a cyclical process of ongoing analysis of student reasoning and simultaneous task design and conjecture modification regarding the possible paths that students' learning might take (Gravemeijer, 1994; Cobb, 2000). The products of classroom teaching experiments often include both theoretical advances (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003) as well as empirically grounded instructional innovations (e.g., Larsen, 2009; Rasmussen & Keynes, 2003; Stephan & Akyuz, 2012). In other words, according to Treffers (1987), the purpose of design research can encompass developing, testing, and revising instructional sequences.

The results we present in this chapter are a case of the latter. That is, we present both an instructional sequence known as the Magic Carpet Ride (MCR) sequence, which was a product of design research within the context of an undergraduate mathematics classroom, and the underlying theoretical rationale for the sequence. The MCR sequence arose as a product of the following research question: What instructional sequence could be created and enacted to foster students' guided reinvention of the concepts of span and linear independence, and how could the sequence leverage students' intuitive knowledge towards the development of more formal ways of reasoning about these two concepts? The MCR sequence and the theoretical basis for it grew out of three semester long classroom teaching experiments at two institutions with three different instructors, each of whom were central members of the research and curriculum development team. In the subsequent section we detail more specifically the iterations of our design research.

## 2. Design and development stage

In general, our design research adheres to the principles illustrated in Figure 1. Our work in instructional design is informed by a theoretical framework (that of Realistic Mathematics Education, detailed in the subsequent Theoretical Framework section). The data collected during task implementation feed the ongoing analysis of the task and of student thinking, and this analysis is grounded in theories of learning and associated research results. The findings from this analysis feed back into the next iteration of the design cycle by informing any refinement or alterations of the task sequence and/or the implementation of the task. More detail about the structure of the specific iterations is given in Figure 2 and the remainder of this section.

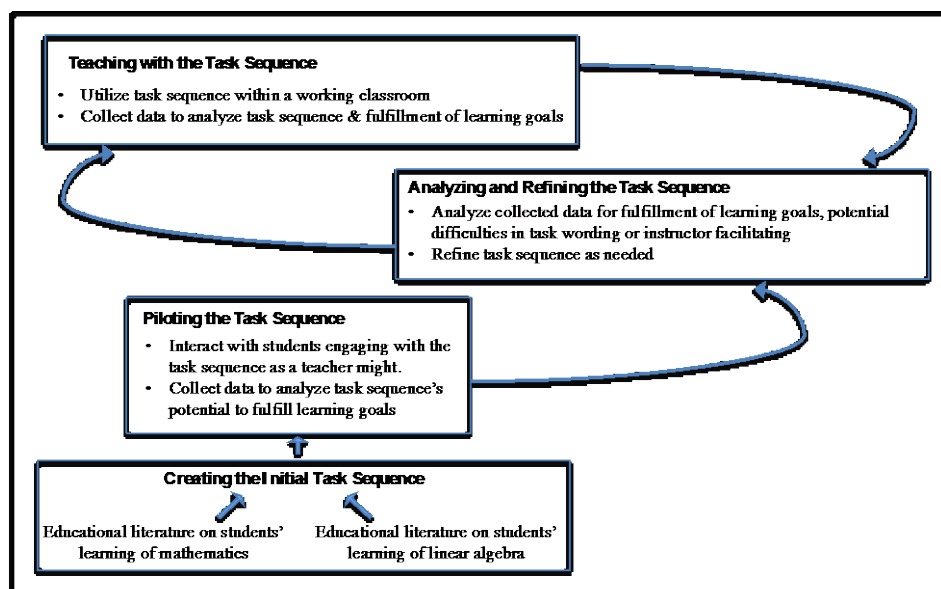


Figure 2: Schematic of the iterative cycle of task implementation and refinement

During the first stage of developing a new task sequence, labeled *Creating the Initial Task Sequence* in Figure 2, we draw on several sources of knowledge and influence. First, we consider the learning goals we have for the students. What mathematical ideas do we want students to develop deep conceptual understanding of, and where do those ideas fit into the broader scope of the course as a whole? We then begin to think about what tasks we could

create that have the potential to facilitate those desired mathematical understandings. This task development is deeply influenced by our belief that tasks should have the potential to elicit students' current/intuitive ways of thinking about mathematical ideas that then can be leveraged towards more formal mathematical reasoning about the concepts involved. The implications of this are captured by Gravemeijer (2004), who states: "For the instructional designer this implies a change in perspective from decomposing ready-made expert knowledge as the starting point for design to imagining students elaborating, refining, and adjusting their current ways of knowing" (p. 106).

At this first iteration of the task sequence, at its creation stage, we cannot be certain how students will engage in it. Thus, we have to draw on our knowledge of student thinking, both in general and in specific. In general, we rely on research regarding how students learn mathematics. For example, Tall and Vinner (1981) introduce the notion of concept image and concept definition as lenses through which to analyze how individual students make sense of particular mathematical concepts. Another example would be to consider development through the lens of participating in mathematical activities such as symbolizing, algorithmatizing, and defining (Rasmussen, Zandieh, King, & Teppo; 2005; Zandieh & Rasmussen, 2010). Specific to linear algebra, we draw on our knowledge of student understanding of particular mathematical concepts from literature or past teaching experiences. For example, literature such as Harel (1997), Stewart and Thomas (2010), Trigueros and Possani (2011), and Wawro (2011) present research regarding students' understanding of span and linear independence. Thus, incorporating these aspects, we write a first draft of the new task sequence.

Next, in general, we pilot the task sequence with a subset of students outside of the actual class (labeled *Piloting the Task Sequence* in Figure 2). This involves a researcher video recording a set of students trying the task, and he/she interacts with them as a teacher might. This data is then reviewed to gain information about how the students engaged with the task. What ways of thinking were elicited? What of these ways of thinking were productive, and which were possibly problematic? Did the task seem to have the potential to facilitate the development of more formal ways of reasoning about the concept(s) involved? We take the information gleaned from analyzing the task's first implementation to inform any possible refinement of the task. This is labeled *Analyzing and Refining the Task Sequence* in Figure 2. We next use the refined task sequence in a classroom environment; this is labeled *Teaching with the Task Sequence* in Figure 2. This begins the second iteration of the design research cycle. This cycle of refining the task and implementing it (seen in the arrows between the upper two boxes in Figure 2) is continued until some balanced state is achieved; of course the task and its implementation are never completely stable, in that an inquiry-oriented classroom requires responsiveness and adaptation to student thinking.

### 3. Theoretical framework

In terms of our theoretical commitments regarding task design, we use as guiding heuristics the principles of Realistic Mathematics Education (RME) (Freudenthal, 1991; Gravemeijer, Bowers, & Stephan, 2003) to create tasks that afford students opportunities to progress along a continuum from informal to more formal ways of reasoning. In particular, our use of RME leverages the RME emergent model design heuristic, in which students first develop *models-of* their mathematical activity, which later become *models-for* more sophisticated mathematical reasoning (Gravemeijer, 1999). Models are defined as student generated ways of organizing their activity with observable and mental tools (Zandieh & Rasmussen, 2010). The shift from model-of to model-for, which is accompanied by the creation of a new mathematical reality or

set of objects, is further explicated with four levels of activity: *situational*, *referential*, *general*, and *formal* (Gravemeijer, 1999; Rasmussen & Blumenfeld, 2007; Zandieh & Rasmussen, 2010). In brief, situational activity involves students working toward mathematical goals in an experientially real setting. Referential activity involves models-of that refer (implicitly or explicitly) to physical and mental activity in the original task setting. General activity involves models-for that facilitate a focus on interpretations and solution processes independent of the original task setting. Finally, formal activity involves students reasoning in ways that are independent of the original setting and reflect the emergence of a new mathematical reality.

For example, in an undergraduate Euclidean and non-Euclidean geometry class, Zandieh and Rasmussen (2010) detail each of these four levels of activity to analyze students' mathematical progress. In Situational activity students used the previous experiences with triangles to create a planar triangle definition, largely based on using their rich concept image of planar triangle. In Referential activity, students' focus was on interpreting a planar triangle definition in the new context of the surface of the sphere. They created examples of spherical triangles and explored possible characteristics of those new triangles, largely in reference to their knowledge of the concept definition and concept image of planar triangle. In General activity, students continued to work on creating the new mathematical reality of triangles on the sphere. The focus of this activity was two-fold. First, students generalized from the examples of spherical triangles they had created and the properties of these triangles noted in Referential activity. Second, students created new definitions, such as for small triangle, that helped delineate new theorems for spherical triangles. In Formal activity, the new mathematical reality of spherical triangles was largely established for these students as they used definitions of triangle congruence and of small triangles on the sphere as part of their justification for steps in proofs that were not directly about triangles.

#### **4. Research agenda and data collection**

Our work is driven by the notion that teaching and research are tightly interrelated, in that one necessarily informs the other. This reciprocal relationship between theory and practice motivates us to investigate how students learn particular ideas in mathematics, as well as to seek out and develop theoretical tools that meet the pragmatic needs of teachers and researchers. The aspect of our research agenda most pertinent to this chapter regards the learning and teaching of linear algebra, specifically with respect to the content of span and linear independence. How do students reason about these concepts, and what curriculum may facilitate students' learning? Other aspects of our research agenda, such as developing methodological tools for documenting the complex nature of mathematical development in the classroom (e.g., Rasmussen, Wawro, & Zandieh, 2012; Rasmussen, Zandieh, & Wawro, 2009), are beyond the scope of this chapter.

The data that we collect in conducting design research includes video recordings of each class session with at least two cameras, copies of student written work during class, copies of all assignments, and individual student interviews conducted at the beginning, middle, and end of the semester. The purpose of the individual interviews varies depending on our progress in developing instructional sequences that enable students to build on their current ways of reasoning. In particular, when we are in the early stages of design research we typically use beginning of the semester individual interviews to gain greater insight into students' intuitive or informal ideas, as well as piloting instructional tasks that will be used in subsequent class sessions. When our instructional sequences are more mature, we typically use beginning of semester individual interviews to test conjectures about students' intuitive or informal thinking.

End of the semester individual interviews, both early and later in our design research, typically assess the extent to which students actually developed in their understanding of the intended concepts.

The classroom video recordings of class sessions capture both small group work and whole class discussions, and this data is reviewed by the research team on a regular basis (at least once per week). This regular, ongoing analysis is structured by the following interests: How were instructional tasks interpreted and how did they function to promote students' mathematical thinking? Are students routinely explaining their thinking listening to others' explanations and challenging or questioning explanations when they are disagree with what others' say? Are small groups functioning well in terms of enabling each student to mathematically contribute and to debate differing points of view? How are particular teacher actions working to create an environment that is conducive to individual and collective mathematical progress? To a large extent, these interests grow out of our theoretical commitments in which learning is viewed as both a social and psychological process (Cobb & Yackel, 1996). Retrospective analysis of the data sources also provides opportunity for theory building about the developing instructional sequence. Regarding the example in this chapter, we used Gravemeijer's (1999) four levels of activity as a starting point to lend form to the MCR, but the refinement of the MCR sequence and its framing within the four levels was made possible by the cyclical process of design research. This is our movement towards building a local instruction theory (Gravemeijer, 1999; Nickerson & Whitacre, 2010).

The data we present in this chapter comes from the third classroom teaching experiment in an introductory linear algebra course during the 2010 spring semester at a large southwestern public university. There were 30 students enrolled in the course, and most had completed three semesters of calculus (at least two semesters was required). Approximately half had also completed a discrete mathematics course, and 75% of students were in their second or third year of university. Most students in the class were majoring in Computer engineering, Computer science, Mathematics, or Statistics.

We begin the remainder of this chapter by describing how our approach of beginning the semester with systems of equations was problematic and thus led to a significant shift. We then detail the result of our shift: the creation of an innovative instructional sequence that supports students' reinvention of the ideas of span and linear independence/dependence. The instructional sequence described here began on the first day of a linear algebra course and facilitates the opportunity for students to intuitively explore the concepts of span and linear in/dependence and reinvent their formal definitions. The chapter concludes with an overview of the theoretical basis for the instructional sequence in terms of the four layers of activity that comprise the RME emergent model heuristic.

## **5. The need for design research**

In our classroom teaching experiments, we work to develop tasks that afford students the opportunity to make significant progress in developing and/or reinventing fundamental mathematical ideas. In our early work in linear algebra, we began the semester by asking students to work on a real-world problem that they were likely to model with systems of linear equations. We chose this approach because of (a) the prevalence in linear algebra textbooks in the United States to begin with systems of equations and Gaussian elimination, and (b) its potential to draw on students' prior knowledge and experiences with systems of equations from coursework in high school or college algebra. Our intent was to use this real-world problem to



introduce alternative notations for modeling the situation, such as matrix equations and vector equations (involving linear combinations of vectors).

Analysis of student interviews conducted during our first classroom teaching experiment, however, revealed a lack of coordination between students' symbolic representations and geometric interpretations of a matrix times a vector (Larson, 2010). For example, students' geometric interpretations were underdeveloped with respect to connecting geometric conceptualization of linear combinations of vectors with matrix multiplication. In our view, this interpretation is particularly important for students in making sense of ideas relating to span, linear dependence and independence.

Our retrospective analysis about students' difficulties points to the original task setting as problematic. It was difficult for students to interpret geometrically, and it did not generalize to situations with non-integer or negative solutions. Furthermore, the problem setting failed to generate a need for notations introduced (such as matrix equation and vector equation notation).

As we planned for subsequent iterations of the teaching experiment, we felt a need for a switch: to begin the semester with a geometrically motivated task that emphasized vectors as the mathematical objects of focus, rather than systems of equations. This would create a need for a geometric interpretation of linear combinations of vectors, which could then be leveraged for ideas relating to span and linear in/dependence. Furthermore, the need to develop more sophisticated solution techniques through systems of equations would emerge naturally from students' work with span and linear in/dependence. We also viewed it as crucial that this context generalize nicely to situations with non-integer valued and negative coefficients. Finally, this alternative problem situation that focuses on vectors as the objects of inquiry and investigation could also be an intuitive starting point for students.

The Magic Carpet Ride sequence, thus, grew out of analysis of student thinking and a reconsideration of our learning goals for the students in the course. With respect to the design cycle explained in Figure 2, the MCR was first created during summer research team meetings. The research team developed the context of travel as a potentially viable one to leverage towards students' development of the notions and vector equations, span, and linear independence. The team debated the development of the specific tasks (such as task wording, symbolism and numerical values to use, etc.). The sequence implementation and refinement cycle illustrated in Figure 2 occurred over three semesters at two institutions with three different instructors, each of whom were central members of the research and curriculum development team. During and after each implementation, the research team would analyze student thinking and the role of the teacher within the development of the classroom mathematics. This led to alterations with the sequence, such as changes in wording of the tasks or key questions that the teacher could ask. The subsequent summary of the MCR, comprises the remainder of this chapter, is the most recent version of the task sequence.

## **6. The Magic Carpet Ride sequence**

The Magic Carpet Ride (MCR) instructional sequence is a set of four tasks that makes use of an experientially real problem setting to support the reinvention of the concepts of span and linear in/dependence. This setting is experientially real for students in that it utilizes both their mathematical knowledge and their experience with travel as a foundation from which to build more formal mathematics. Further details about the sequence can be found in Wawro,

Rasmussen, Zandieh, Sweeney, and Larson (2012). Furthermore, we emphasize how the RME heuristic of emergent models and Gravemeijer's (1999) four levels of activity are manifested within the MCR. This is summarized in Table 1; the specific associated details of the MCR as explored within the body of the text.

In Table 1, the left column provides a description of each level of activity, and the right column describes each level's manifestation within the MCR. Situational activity, which involves students working toward mathematical goals in an experientially real setting, occurs within Tasks 1, 2, and 3. Referential activity involves models-of that refer to physical and mental activity in the original task setting. Tasks are asked without specific reference to the original task setting, but students refer to that setting in solving the tasks. General activity involves models-for that facilitate a focus on interpretations and solutions independent of the original task setting. Finally, formal activity involves students reasoning in ways that reflect the emergence of a new mathematical reality and that no longer requires support of models-for activity.

The first task in the MCR sequence is given to students on the first day of class, prior to any formal instruction. The four tasks that comprise the MCR typically take five to six class sessions to complete. Small group work is alternated with whole class discussions in which students explain their tentative progress, listen to and make sense of other groups' progress, and come to justified conclusions on the problems. Most tasks within the MCR allow for multiple solution strategies and representations. These aspects are fundamental to the efficacy of the instructional sequence in supporting students' reinvention of the mathematical concepts. We detail the MCR instructional sequence by summarizing each of the four tasks and providing examples of student work on those tasks. We also describe how each task relates to the four levels of activity within the emergent models heuristic.

Table 1: The MCR sequence summarized via Gravemeijer's four levels of activity

Level of Activity	Manifestation in the Magic Carpet Ride sequence
<b>Situational Activity</b> involves students working toward mathematical goals in an experientially real setting.	Students explore different ways of combining travel vectors algebraically and geometrically in the Magic Carpet Ride scenario. This occurs within Tasks 1, 2 and 3.
<b>Referential Activity</b> involves models-of that, implicitly or explicitly, refer to physical and mental activity in the original task setting.	Students explore the definitions of linear dependence, linear independence, and span for sets of vectors. Tasks are asked without specific reference to the original task setting, but students refer to that setting in solving the tasks. This occurs within Task 4 and in follow-up questions in Tasks 2, 3, and 4.  Students' organizing activity with the definition and associated concept images of span and linear in/ function as <b>models-of</b> students' activity in the Magic Carpet Ride setting.

Table 1: The MCR sequence summarized via Gravemeijer's four levels of activity (continued)

Level of activity	Manifestation in the Magic Carpet Ride sequence
<p><b>General activity</b> involves models-for that facilitate a focus on interpretations and solutions independent of the original task setting.</p>	<p>Students make and support conjectures about properties of sets of vectors regarding linear dependence, linear independence, and span.</p> <p>The new mathematical reality of <math>\mathbb{R}^n</math> emerges. Students' organizing activity with the definitions and concept images of span and linear in/dependence function as <b>models-for</b> enlarging the new mathematical reality of <math>\mathbb{R}^n</math> and making new generalizations about sets of vectors in <math>\mathbb{R}^n</math> that do not refer to the MCR setting.</p>
<p><b>Formal activity</b> involves students reasoning in ways that reflect the emergence of a new mathematical reality and consequently no longer require support of prior models-for activity.</p>	<p>Students use definitions of span, linear dependence and linear independence without having to unpack the meanings of these definitions (e.g., use definitions to reason about the Invertible Matrix Theorem). Does not occur during Tasks 1-4 of the MCR sequence, but rather occurs during the remainder of the semester on tasks unrelated to the MCR sequence.</p>

### Task 1: Investigating vectors and their properties

A main goal of Task 1 (see Figure 3) is promote students' understanding of vectors and their properties. The instructor uses student work as a starting point for introducing formal notation and language for scalar multiplication, linear combinations, vector equations, and system of equations. In Task 1, students are presented with a scenario in which they are preparing to embark on a journey, and they are given two modes of transportation - a magic carpet and a hover board. They are asked to investigate whether it is possible to reach a certain location - the location where Old Man Gauss lives - with the two modes of transportation. The movement of the magic carpet, when ridden forward for a single hour, is denoted by the vector  $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$  to indicate motion along a "diagonal" path resulting from displacement of 1 mile East and 2 miles North. The other mode of transportation, a hover board, is defined similarly along the vector  $\begin{bmatrix} 3 \\ 1 \end{bmatrix}$ . The problem as given to students is shown in Figure 2.

### THE MAGIC CARPET RIDE PROBLEM

You are a young traveler, leaving home for the first time. Your parents want to help you on your journey, so just before your departure, they give you two gifts. Specifically, they give you two forms of transportation: a hover board and a magic carpet. Your parents inform you that both the hover board and the magic carpet have restrictions in how they operate:



We denote the restriction on the *hover board's* movement by the vector  $\begin{bmatrix} 3 \\ 1 \end{bmatrix}$ .

By this we mean that if the hover board traveled "forward" for one hour, it would move along a "diagonal" path that would result in a displacement of 3 miles East and 1 mile North of its starting location.



We denote the restriction on the *magic carpet's* movement by the vector  $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$ .

By this we mean that if the magic carpet traveled "forward" for one hour, it would move along a "diagonal" path that would result in a displacement of 1 mile East and 2 miles North of its starting location.

#### PROBLEM ONE: THE MAIDEN VOYAGE

Your Uncle Cramer suggests that your first adventure should be to go visit the wise man, Old Man Gauss. Uncle Cramer tells you that Old Man Gauss lives in a cabin that is 107 miles East and 64 miles North of your home.

#### TASK

Investigate whether or not you can use the hover board and the magic carpet to get to Gauss's cabin. If so, how? If it is not possible to get to the cabin with these modes of transportation, why is that the case? Use the vector notation for each mode of transportation as part of your explanation. Use a diagram or graphic to help illustrate your point(s).

Figure 3: Task 1 of the Magic Carpet Ride sequence

With respect to the first of the four levels of activity, Situational activity involves students working toward mathematical goals in an experientially real setting. Within Task 1, this is evidenced as students explore different ways of combining travel vectors in  $\mathbb{R}^2$  (the set of all vectors  $\begin{bmatrix} x \\ y \end{bmatrix}$  with  $x$  and  $y$  as real numbers) towards the goal of determining how to reach Old Man Gauss. This activity helped students explore the notion of a linear combination of one or two vectors in  $\mathbb{R}^2$ , including its symbolic and graphical representations. Thus, even at this level students develop symbolic and graphical inscriptions that are models of their thinking.

As students share their work and solution strategies, an opportunity to coordinate geometric and algebraic views of the problem and its solution is given. The class begins by exploring the problem setting; for instance, riding the magic carpet forward for three hours would transport you to 3 miles East and 6 miles North of the starting point, and that could be denoted as  $3 \begin{bmatrix} 1 \\ 2 \end{bmatrix}$  or  $\begin{bmatrix} 3 \\ 6 \end{bmatrix}$ . Also, a negative scalar with a vector, such as  $-4 \begin{bmatrix} 3 \\ 1 \end{bmatrix}$ , would be interpreted as traveling "backward" or "in reverse direction" on the hover board for 4 hours, and a fractional scalar would translate to travelling for portions of an hour. By sharing their approaches, students have the

opportunity to see the problem in multiple ways and make new connections between their thinking and other possible approaches. This also allowed the instructor to highlight important ideas and connections. For example, the instructor used student work to make explicit how to transition between vector equations, systems of equations, and various geometric representations. Student work is described in more detail in Wawro et al. (2012).

### Task 2: Reinventing the notion of span

The goal of Task 2 is to help students develop the notion of span in a two-dimensional setting before formalizing the concept with a definition. Task 2 prompts students to determine whether there is any location where Old Man Gauss can hide so that they would be unable to reach him using the same two modes of transportation from Task 1 (see Figure 4). With respect to the four levels of activity, Task 2 first engages students in situational activity as they work to determine if Old Man Gauss can hide. This activity involves students working to find a way to think about *all* possible linear combinations of vectors, thus leading to the reinvention of the notion of span. Follow-up questions that the instructor poses regarding span position students to engage in referential activity. Referential activity involves making use of tools, inscriptions, and ideas that refer (implicitly or explicitly) to physical and mental activity in the original task setting. As detailed in this section, this occurs as students referred back to the MCR scenario to reason about the span of non-situational vectors.

THE MAGIC CARPET RIDE: PROBLEM TWO

**SCENARIO TWO: HIDE-AND-SEEK**

Old Man Gauss wants to move to a cabin in a different location. You are not sure whether Gauss is just trying to test your wits at finding him or if he actually wants to hide somewhere that you can't visit him.

**Are there some locations that he can hide and you cannot reach him with these two modes of transportation?** Describe the places that you can reach using a combination of the hover board and the magic carpet and those you cannot. Specify these geometrically and algebraically. Include a symbolic representation using vector notation. Also, include a convincing argument supporting your answer.

Use your group's whiteboard as a space to write out your work as you work together on this problem.

Figure 4: Task 2 of the Magic Carpet Ride sequence

In spring 2010, after working on Task 2 in small groups, determining if Old Man Gauss could hide became reinterpreted as determining if you could “get everywhere” with the two modes of transportation, and there was disagreement as to whether it was in fact possible to “get anywhere.” Students wrestled, in productive ways, with their interpretations of vector addition, scaling, and linear combinations of vectors and the variety of ways they might appear in geometric depictions. Figure 5 provides two examples of student work on Task 2. In Figure 5(a), Group 1 concluded that, with the two modes of transportation, only locations within the shaded regions, which we refer to as a “double cone,” could be reached; thus, Old Man Gauss could hide anywhere outside of the shaded regions. Group 4 (Figure 5(b)), on the other hand, argued that you could “get anywhere” in the entire plane with the two modes of transportation. Student work is described in more detail in Wawro et al. (2012).

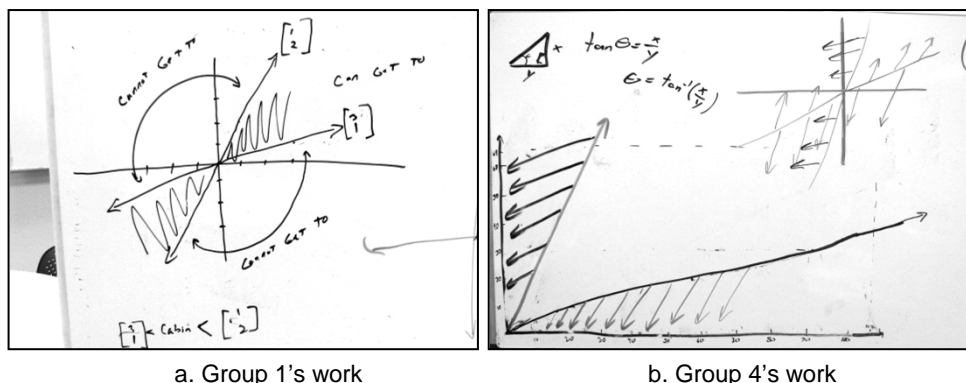


Figure 5: Samples of student solutions to the second task

After student approaches had been discussed in class, the instructor introduced the language and formal definition of span in relation to the work and ideas set forth by students. She stated the span of a set of vectors is all possible linear combinations of those vectors, or in other words, all places you could reach with those vectors. Furthermore, any vector that can be written as  $c_1\mathbf{v}_1 + c_2\mathbf{v}_2 + \dots + c_p\mathbf{v}_p$  for some real numbers  $c_1, c_2, \dots, c_p$  is in the span of  $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_p\}$ . The instructor's introduction of a new term and its definition functioned to support students in shifting from situational activity (working within the MCR context) to referential activity (working with the idea of span, which was motivated by students' prior work of determining if Old Man Gauss could hide).

Next, the instructor asked if Gauss's location from Task 1, the vector  $\begin{bmatrix} 107 \\ 64 \end{bmatrix}$ , was in the span of  $\left\{ \begin{bmatrix} 1 \\ 2 \end{bmatrix}, \begin{bmatrix} 3 \\ 1 \end{bmatrix} \right\}$ , the two modes of transportation. The class decided that it is in the span because there exists scalars, namely 30 and 17, such that  $30 \begin{bmatrix} 3 \\ 1 \end{bmatrix} + 17 \begin{bmatrix} 1 \\ 2 \end{bmatrix} = \begin{bmatrix} 107 \\ 64 \end{bmatrix}$ . The instructor then posed new questions about span for the students to consider within their small groups. A variety of responses were shared in whole class discussion. For example, the class determined the span of  $\left\{ \begin{bmatrix} 1 \\ 3 \end{bmatrix}, \begin{bmatrix} 2 \\ 6 \end{bmatrix} \right\}$  is not all of  $\mathbb{R}^2$  because you cannot "get everywhere" with those two vectors; rather, you can only "travel" along the line through those vectors. The way many students engaged in these was referential because they made reference to the MCR scenario in solving the problems (which were not in the task setting). In addition to responding to the posed questions, a few groups also developed conjectures about span in a more general way. For instance, two groups developed a generalization that two vectors in  $\mathbb{R}^2$  that are not scalar multiples span  $\mathbb{R}^2$ . This indicates an initial movement towards general activity because these groups were reasoning about properties of sets of vectors.

### Task 3: Reinventing linear independence/dependence

The purpose of Task 3 is to provide an opportunity for students to develop geometric imagery for linear dependence and linear independence that can be leveraged in the development of the formal definitions of these concepts. In Task 3, students are asked to determine if, using three vectors that represent modes of transportation in a three-dimensional world, they can take a journey that starts and ends at home (see Figure 6). The restrictions placed on the movement of these modes of transportation are that the vectors can only be used once for a fixed amount of time represented by the scalars  $c_1, c_2,$  and  $c_3$ . With respect to the four levels of activity, Task 3 first engages students in situational activity as they investigate existence and uniqueness of solutions to homogeneous equations by considering "journeys that begin and end at home." In

whole class conversations following students' work on Task 3, the instructor supports students' engagement in referential activity by posing follow-up questions that allow them to use their experience with the MCR scenario to justify claims about linear in/dependence for non-situational examples.

**THE CARPET RIDE PROBLEM: DAY THREE**

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**SCENARIO THREE: GETTING BACK HOME**

Suppose you are now in a three-dimensional world for the carpet ride problem, and you have three modes of transportation:  $\mathbf{v}_1 = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$ ,  $\mathbf{v}_2 = \begin{bmatrix} 6 \\ 3 \\ 8 \end{bmatrix}$ ,  $\mathbf{v}_3 = \begin{bmatrix} 4 \\ 1 \\ 6 \end{bmatrix}$ .

You are only allowed to use each mode of transportation **once** (in the forward or backward direction) for a fixed amount of time ( $c_1$  on  $\mathbf{v}_1$ ,  $c_2$  on  $\mathbf{v}_2$ ,  $c_3$  on  $\mathbf{v}_3$ ). Find the amounts of time on each mode of transportation ( $c_1$ ,  $c_2$ , and  $c_3$ , respectively) needed to go on a journey that starts and ends at home OR explain why it is not possible to do so.

Figure 6: Task 3 in the Magic Carpet Ride sequence

In Spring 2010, initial progress on Task 3 was made when the class established that a trip that begins and ends at home can be represented by  $c_1 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} + c_2 \begin{bmatrix} 6 \\ 3 \\ 8 \end{bmatrix} + c_3 \begin{bmatrix} 4 \\ 1 \\ 6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$ . By formulating the problem in this way, students were able to connect their algebraic activity of previous tasks to their work on this problem. Examples of student work are given in Wawro et al. (2012).

Whole class discussion of the various approaches offered insight into how students conceptualized linear combination of the three vectors. The language of "getting back home" came to represent movement along the vectors and how to combine the vectors so that the journey returned to the origin. The instructor labeled the ability to "get back home" with the term linearly dependent and subsequently introduced the formal definition as follows: Given a set of vectors  $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_p\}$  in  $\mathbb{R}^n$ , if there exists a solution to the equation  $c_1\mathbf{v}_1 + c_2\mathbf{v}_2 + \dots + c_p\mathbf{v}_p = \mathbf{0}$  where not all  $c_1, c_2, \dots, c_p$  are zero, then  $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_p\}$  is a linearly dependent set.

Next, the instructor asked if a set that contained the travel vectors from Task 1, namely  $\left\{ \begin{bmatrix} 1 \\ 2 \end{bmatrix}, \begin{bmatrix} 3 \\ 1 \end{bmatrix} \right\}$ , was linearly dependent. In this discussion, many students did not appeal to the formal definition of linear dependence. Instead, they referenced "getting back home" as how they knew that the vectors were not linearly dependent. To justify why  $\left\{ \begin{bmatrix} 1 \\ 2 \end{bmatrix}, \begin{bmatrix} 3 \\ 1 \end{bmatrix} \right\}$  was not linearly dependent, another student demonstrated that by placing these two vectors into the appropriate system of equations, the scalars  $c_1$  and  $c_2$  would be forced to be zero. The instructor then tagged the set of these two vectors as linearly independent and introduced the formal definition as follows: A set of vectors  $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_p\}$  in  $\mathbb{R}^n$  is a linearly independent set if the only solution to the equation  $c_1\mathbf{v}_1 + c_2\mathbf{v}_2 + \dots + c_p\mathbf{v}_p = \mathbf{0}$  is if all  $c_1, c_2, \dots, c_p$  are zero. The instructor's work in tagging with a new definition functioned as a bridge between students' prior work and the conventional mathematical term. It also supported students' engagement in referential activity as they engaged in follow-up problems that utilized the new terminology.

#### Task 4: Creating Examples of Linearly Independent and Dependent Sets

One main goal of Task 4 is to shift students away from situational and referential activity with respect to the Magic Carpet Ride scenario towards a general level of activity with respect to linear in/dependence. In Task 4, students are asked to generate examples of linearly dependent and linearly independent sets of vectors in  $\mathbb{R}^2$  and  $\mathbb{R}^3$ . Task 4 also prompts students to make generalizations, however tentative, regarding conditions for a set of vectors to be linearly independent or dependent (see Figure 10).

<b>LINEAR INDEPENDENCE AND DEPENDENCE: CREATING EXAMPLES</b>		
<i>Fill in the following chart with the requested sets of vectors.</i>		
	Linearly dependent set	Linearly independent set
A set of 2 vectors in $\mathbb{R}^2$		
A set of 3 vectors in $\mathbb{R}^2$		
A set of 2 vectors in $\mathbb{R}^3$		
A set of 3 vectors in $\mathbb{R}^3$		
A set of 4 vectors in $\mathbb{R}^3$		
<i>Write at least 2 generalizations that can be made from this table</i>		

Figure 7: Task 4 in the Magic Carpet Ride sequence

As students completed the chart in Figure 7, they developed various generalizations about linear in/dependence. The four conjectures listed below, which occurred during the spring 2010 semester, represent typical responses.

1. If you have a set of vectors in  $\mathbb{R}^n$  where two of the vectors are multiples of each other, then the set is linearly dependent.
2. If any vector in the set can be written as a linear combination of the other vectors, then the set is linearly dependent.
3. If the zero vector is included in a set of vectors, then the set is linearly dependent.
4. If a set of vectors in  $\mathbb{R}^n$  contains more than  $n$  vectors, then the set is linearly dependent.

The first two were quickly justified by students. The third and fourth conjectures, however, required more debate and justification. For instance, one group suggested that  $\left\{ \begin{bmatrix} 1 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 3 \end{bmatrix}, \begin{bmatrix} 0 \\ 0 \end{bmatrix} \right\}$  was linearly independent, whereas another suggested that there was no possible set of three vectors in  $\mathbb{R}^2$  that could be linearly independent. After the class established that not both could be correct, the instructor asked for volunteers to support either conclusion. Some students referred to the formal definition of linear dependence to justify why any set containing the zero vector must be linearly dependent. With respect to the four levels of activity, the class' use of the definition of linear dependence to determine that any set with the zero vector would be linearly dependent is an example of a general level of activity. This is general activity because the students worked with vectors without referring back explicitly to the MCR scenario as they explored properties of sets of vectors in  $\mathbb{R}^2$ . This was then followed by referential activity in that the class explicitly referred back to the MCR scenario in order to develop a rich understanding of properties of sets that contain the zero vector.



Next, the class discussed whether a group was correct in conjecturing that there was no set of three vectors in  $\mathbb{R}^2$  that was linearly independent. Justin, a member of that group, supplied an argument to the class to justify this assertion. Later that day, Justin claimed any set of vectors in  $\mathbb{R}^n$  that contained more than  $n$  vectors was linearly dependent. He explained how an analogous argument applies for  $\mathbb{R}^n$ , using  $\mathbb{R}^3$  as an example of how the argument generalizes to other dimensions. Justin engaged in referential and general activity to develop and justify generalizations. To explain his conjecture that any set in  $\mathbb{R}^2$  with more than two vectors was linearly dependent, he first referred to the MCR scenario (specifically to activity within Task 2). He then engaged in general activity as he extended his conjecture to sets of vectors in  $\mathbb{R}^n$  that contained more than  $n$  vectors.

### **Beyond the Magic Carpet Ride sequence: Formal level of activity**

Formal activity involves students reasoning in ways that reflect the emergence of a new mathematical reality and consequently no longer require support of prior models-for activity. Students use definitions of span and linear in/dependence without having to unpack the meanings of these definitions. We provide one example of formal level of activity. One student, Abraham, during an individual interview at the end of the semester, was asked to explain how he understands the equivalence of the two statements “The number zero is not an eigenvalue of  $A$ ” and “The null space of  $A$  contains only the zero vector.” A portion of his response is given:

An eigenvalue definition something's like, there's a nonzero  $\mathbf{x}$  such that  $A\mathbf{x} = \lambda\mathbf{x}$ . And so if the number zero...this says 'not.' But I always like to think of if it *is*. So then if it *is*, if, if  $\lambda = 0$ , then  $A\mathbf{x} = \mathbf{0}$ . And then by the definition of an eigenvector, we can find a nonzero solution...So then if  $\lambda = 0$ , this is saying by the definition, we can find a nonzero solution, such that  $A\mathbf{x} = \mathbf{0}$ . But this is, it's linear dependent, by definition, because it's a nontrivial or the only solution is not the trivial solution. There's a nonzero solution, so it's linear dependent if it's [the eigenvalue] zero. And how does this relate to null space for me? ... I think of this because if there's a nonzero solution here, then the null space doesn't contain only the zero vector.

The underlined portion highlights his use of the definition of linear dependence to reason about how having zero as an eigenvalue of  $A$  implies that the null space of  $A$  contains more than just the zero vector. To do this, he did not need to unpack the meaning of linear dependence, as was done earlier in the semester. He did not need to refer back to the MCR sequence to reason about linear dependence. Rather, he was able to use its definition without unpacking it to support claims about new concepts in linear algebra.

## **7. Conclusion**

Within this chapter we detailed an example of design research within undergraduate mathematics. In particular, the results we presented here were a research-based instructional sequence known as the Magic Carpet Ride sequence, which fosters students' reinvention of span and linear in/dependence, and its underlying theoretical rationale. Our methodological approach to design research is informed by Cobb (2000), which details methodology for classroom teaching experiments. Theoretically, our work is grounded in Realistic Mathematics Education. Within this chapter, we emphasized how the RME heuristic of emergent models and Gravemeijer's (1999) four levels of activity informed the creation of the MCR. We conclude with a summary of the levels of activity as manifested in the MCR.

Within Table 1, the left column provides a description of each level of activity, and the right column describes each level's manifestation within the MCR. Situational activity, which involves students working toward mathematical goals in an experientially real setting, occurs within

Tasks 1, 2 and 3. In Task 1, students determine how to reach Old Man Gauss. In Task 2, students determine if Old Man Gauss can hide, and in Task 3, students determine how to begin and end a journey at home. In addition, students develop symbolic and graphical inscriptions that are models-of their thinking and that the instructor is able to label with the terminology of the mathematical community such as linear combination, span, and linear in/dependence. Referential activity involves models-of that refer to physical and mental activity in the original task setting. In the follow-up questions within Tasks 2 and 3, students explore the definitions of span and linear in/dependence. Tasks are asked without specific reference to the original task setting, but students refer to that setting in solving the tasks. Within Task 4, in which students are asked to create examples of sets of vectors, they often refer back to the MCR scenario to create their examples as well as justify why their examples are valid. General activity involves models-for that facilitate a focus on interpretations and solutions independent of the original task setting. In addition to creating examples in Task 4, students are prompted to develop conjectures about linearly in/dependent sets. This is general activity because the students reason about general properties of sets vectors without referring back explicitly to the MCR scenario.

Creating a new mathematical reality of  $\mathbb{R}^n$  begins in referential activity as students explore what it means to "get everywhere" or to "get back home." When the instructor tags these activities with formal definitions of span and linear in/dependence, these definitions and the associated concept images become models of student activity in the task setting. This is the beginning of creating the new mathematical reality. When students are asked to work explicitly with the definitions to answer questions about span and linear in/dependence, the students are transitioning to general activity, in which the definitions serve as models for their organizing activity. In general activity students create conjectures using the definitions and new concept images associated with these definitions. This further develops the new mathematical reality of  $\mathbb{R}^n$ .

Finally, formal activity involves students reasoning in ways that reflect the emergence of a new mathematical reality and that no longer requires support of models-for activity. Formal activity occurs later in the semester as students are able to use definitions in the service of making other arguments without having to explicitly recreate or reinterpret those definitions. We provided one example of Abraham using the definition of linear dependence to explain a connection between Eigen theory and null space.

Although retrospective analysis of the data is ongoing, initial analysis suggests that using the MCR sequence as an avenue for investigating span and linear in/dependence, which then leads to a need for complex systems of equations, ameliorated our initial issues to a certain extent. Additional future research involves investigating the instructor's actions, such as how and when to introduce definitions that connect to students' prior activity, that support shifts in students' levels of activity.

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## Employing a Three-phase Design-based Research Methodology for Expanding Student Teachers' Language-related Literacy Practices in an Egyptian Pre-service English Education Programme

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# 43. Employing a three-phase design-based research methodology for expanding student teachers' language-related literacy practices in an Egyptian pre-service English education programme

Mahmoud Abdallah

## Abstract

*The chapter reports on a case of a research study that investigates the possibility of expanding Egyptian pre-service EFL student teachers' language-related literacy practices by integrating some web-based new literacies into their education programme.*

*After an overview of the rationale, objectives, and research problem, a detailed argument is provided to rationalise the choice of DBR for the purposes of the study based on some epistemological considerations, and to explain why it has been preferred to other prominent research methodologies (e.g., experimental design, interpretivist research, and action research). Moreover, a special focus is given to pragmatism as a basis of DBR. This is followed by a review of the specific design-based research (DBR) methodology employed (i.e. a three-stage research framework): (1) the preliminary phase, which acts as a theoretical and empirical foundation; (2) the prototyping phase of two iterations; (3) the assessment/reflective phase presenting a final design framework for expanding EFL student teachers' language-related literacy practices.*

*My main focus here is on the three-phase research design and the procedures followed in the prototyping phase to highlight DBR as a process, and thus provide readers with a practical, contextual example of how DBR can be employed in reality by doctoral students.*

## 1. Introduction and rationale

Globally speaking, current advances in modern technologies have created a need for reconceptualising old notions of literacy centred on the ability to read, write, and comprehend printed texts, especially within language learning contexts. The Internet calls for new forms of reading, writing, and communication in this information age.

Today, literate individuals should know how to gather, analyse, and use information resources to solve problems and accomplish certain goals. This has become crucial within English language learning (ELL) contexts where learners are required to use English for a variety of communicative and functional purposes.

As far as language teacher education is concerned, new literacies have become of great concern in educational institutions. Nowadays, teachers in the field face many challenges related to technology and literacy. They are challenged to engage students in emerging new literacies (e.g., online reading and writing), which can be regarded as natural extensions of the traditional linguistic aspects. Teacher education is the means through which new literacies can be integrated (Abdallah, 2011b).

## 2. Problem of the study

My identification of the problem started while I was administering my MA programme on oral language skills to a group of EFL student teachers in Egypt, which I reported in a recent book (Abdallah, 2010). These interactions fostered a feeling that the learners needed to expand their literacy practices by integrating the Web into their education programme.

Further, I conducted a short investigation (Abdallah, 2011a) with a purposive sample of 30 EFL teacher educators and senior student teachers that was seen as sufficiently representative for Assiut University College of Education (AUCOE) in Egypt. In response to online semi-structured interviews, all participants indicated that EFL student teachers at AUCOE: (1) did not receive any training in the college on using the Web for ELL purposes; (2) were not provided with adequate or systematic opportunities to use the Web throughout their education programme; (3) believed in the great promise the Internet holds for ELL; and (4) experienced difficulties in using the Web for academic purposes (Abdallah, 2011a).

A review of EFL programmes in Egypt reveals that the knowledge base represented in the undergraduate courses is not sufficiently updated to address Web-based new literacies and applications in English language teaching (ELT) and ELL. Similarly, a review of empirical studies conducted in the Egyptian context reveals a lack of theorisation regarding the implementation of ICTs in general and the Web in particular, for educational and language learning purposes, especially in the context of pre-service EFL teacher education (Abdallah, 2011b).

From a curriculum design perspective, EFL curricula in the pre-service teacher education programmes, with specific reference to AUCOE, are pre-designed from a 'fidelity' perspective that requires abiding by strict rules and guidelines during implementation regardless of the specific context, rather than from an 'enactment' perspective that considers the real teaching-learning process in schools as a major resource for informing the curriculum design process. Thus, EFL student teachers at AUCOE lack the necessary knowledge, competencies, and skills required to use the Web for language learning purposes. Hence, a design framework that involves principles and guidelines for expanding EFL student teachers' language-related literacy practices by integrating some Web-based new literacies into the target context, is sought through the study.

## 3. Research objectives and questions

The objective of the study was to explore the possibility of expanding the language-related literacy practices for Egyptian EFL student teachers in the context of their pre-service education programme, with specific reference to AUCOE, by integrating some Web-based new literacies into this programme. Accomplishing this aim can be realised through the accomplishment of some objectives represented in:

1. Identifying those Web-based new literacies that EFL student teachers currently need as well as those Web-based facilities useful to them, and why and how they might be useful in this context;
2. Establishing a design framework that includes principles and guidelines for expanding Egyptian EFL student teachers' language-related literacy practices.
3. Generating implications that inform the curriculum design process within Egyptian pre-service EFL teacher education programmes.
4. Introducing new methodologies and products into the Egyptian context (e.g., DBR).

To realise the objectives described above, the following questions were addressed:

1. What is the range of Web-based new literacies that Egyptian EFL student teachers need in the context of their pre-service teacher education programmes to cope with the increasing use of ICTs in TEFL?
2. Which Web-based facilities are beneficial to Egyptian EFL student teachers, and why and how can they be beneficial?
3. Which design principles are effective as guidelines for expanding the language-related literacy practices of Egyptian EFL student teachers at AUCOE through integrating some Web-based new literacies into their education programme?
4. What are the implications of the suggested design principles for EFL curriculum design in the target context of AUCOE?
5. What are the methodological implications of employing an educational design-based research (DBR) methodology along with some innovative techniques for data collection and analysis, for the Egyptian context of educational enquiry?

#### 4. Research methodology and procedures

##### Rationale and range of possibilities

The research objectives and questions discussed above entail generating a design framework that includes some design principles to be tested through short interventions. To realise this main goal, a range of research methodologies could be used, such as experimental research, action research, and formative evaluation, all of which sound similar to design-based research (DBR).

The experimental research design (ERD) is the most popular approach in Egypt. At first glance, ERD seems an appropriate design since it involves pre-post testing. However, it is not the right fit for two main reasons: (1) In ERD researchers want to compare an experimental group with a control group. It is not 'fair' to place an innovative intervention that is still in a 'prototype' stage in an experiment 'against' a control situation; (2) when one strives in an intervention for 'innovative' educational goals, there might not be an appropriate control situation for an experiment. It is often better to apply a 'criterion-referenced' approach (i.e. test the intervention against the required goals) (Nieveen, 2009; Plomp, 2009)

Realising this problematic issue, Brown (1992) and Kelly (2007) present some major differences that distinguish the two approaches (see Table 1):

Table 1: Comparison of experimental design and design-based research

Category	Experimental research	Design-based research
Orientation	Controls variables	Characterises the situation
Location	Artificial laboratory settings	Messy, natural learning/teaching situations
Procedures	Follows fixed procedures	Follows flexible procedures to refine designs
Learning	Values isolated learning	Values social interaction
Hypotheses Testing	Tests hypotheses	Generates/Cultivates hypotheses

At the other extreme, the interpretivist research paradigm (IRP) seems a good alternative. However, despite the in-depth analytical accounts it provides, IRP does not interfere directly to change or improve educational reality by examining theory in context.

In terms of connecting theory to practice, action research and formative research are two approaches which seem similar to DBR, and hence might be appropriate for my purposes. Some researchers confuse DBR with action research, but what makes DBR different is that it does not simply aim to refine a design intervention toward improving practice, but also to refine theory and provide some useful design principles (Bielaczyc & Collins, 2007). In addition, in DBR there is an engineering approach to design, especially as far as computer environments and innovations are concerned. This emphasis in particular might take DBR away from action research.

Formative evaluation is closely related to DBR since both are naturalistic, process-oriented, and iterative involving creating tangible designs that work in complex social settings. However, formative evaluation does not entail theory generation as a goal; rather, its goal is to improve the practice of design (Barab & Squire, 2004).

Generally, DBR is convenient when there is an intent to produce new theories that account for learning/teaching in naturalistic settings (Barab & Squire, 2004), and to provide insights and contributions for improving educational practice (Plomp, 2009). In this way, it functions as a means of bridging the gap between theory and practice by addressing real educational problems based on which design frameworks are developmentally formulated and enacted. Moreover, since improving educational practice, especially in teacher education, has become an important aim of research in Egypt, there is a need to introduce DBR as a new paradigm that aims at improving both theory and practice, and as a means of building local theories based on realistic practices and interactions in the context.

In this sense, educational DBR can be more appropriate than ERD, which has not succeeded in producing strong theoretical arguments and rigorous results that link theory to practice, or presenting principles for practitioners to consult when faced with practical problems, especially in the Egyptian context. The nature of the curriculum and methodology topics in the Egyptian context needs a flexible paradigm under which some quantitative and qualitative methods can be combined to achieve certain objectives (Abdallah, 2011b).

Drawing on the above arguments, DBR appears the most suitable paradigm here for the following reasons:

1. Research objectives should inform the choice of methodology, not the other way around. Thus, researchers must be eclectic in their search for truth (Pring, 2005), choosing the paradigm and methods that fit in with their research objectives.
2. DBR addresses complex problems whose solutions cannot be easily suggested without investigating the context and experimenting with preliminary designs (Plomp, 2009). The study addresses a complicated problem for which there are no ready solutions.
3. DBR draws upon the ontological and epistemological assumptions of pragmatism that differentiate it from both interpretivism and positivism (Creswell, 2003).
4. The study targets expanding language-related literacy practices, which requires a new research methodology (Bielaczyc & Collins, 2007). DBR begins with the basic assumption that existing educational practices are inadequate, or can, at least, be improved.

5. DBR was originally used for designing models to address emerging technological innovations. My main focus on Web-based new literacies is part of those innovations.
6. Pre-service EFL teacher education, where prospective teachers need to continuously develop their teaching/learning skills and educational practices, is an ideal context for conducting DBR (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003).
7. EFL curriculum design is a main concern in the study. DBR contributes to three types of outputs: design principles, curricular products, and professional development of participants (Abdallah, 2011b).

### **Ontology and epistemology: Pragmatism as a basis for DBR**

Any research process involves a particular view of the world and the nature of social reality that guides the researcher's choice of research paradigm, methodology, methods, and procedures. Grix (2004) argues that there are four main building blocks of research that are closely interrelated: ontology (i.e. the existence of something out there to know); epistemology (i.e. the means through which we can know about it); methodology (i.e. how we can go about acquiring that knowledge); methods (i.e. the precise procedures to be used to acquire it); and sources (i.e. the specific data that should be collected).

As far as DBR is concerned, any discussion of ontology should address the 'ontological innovation' concept devised by DiSessa and Cobb (2004) to express the continuous refinement of theoretical claims in reality to explain how the world works. The term means the "attributions we make to the world that necessarily participate in our deepest explanatory frameworks" (DiSessa & Cobb, 2004, p.84), and as a result, we find and validate a new category of existence.

This entails a pragmatic, contextual view of knowledge as an interactive process that involves many factors (e.g., personal, mental, and social), and therefore, its formation cannot be studied in isolation. In this regard, Crotty (2003, p.64) argues that "what is said to be 'the way things are' is really just 'the sense we make of them'". The quite different worlds which people inhabit constitute diverse ways of knowing and different sets of meanings.

Research should address questions of genuine interest to educators and the findings should involve useful implications for practitioners, and thus, a link should be made between theory and practice. Unlike many other disciplines (e.g., physical sciences) that employ scientific methodologies, educational research has social dimensions (Crotty, 2003; Pring, 2005) since it is conducted to address learning as a social phenomenon. However, the philosophical assumptions underlying educational research, such as claims about the duality between mind and matter (Crotty, 2003), or between "the objective world of physical things and the subjective world of meanings" (Pring, 2005, p.33), can cause difficulties for both researchers and practitioners, many of whom avoid such complicated arguments for the sake of focussing on practical research issues (Tashakorri & Teddlie, 1998).

As an alternative to the mind-matter dualism, the pragmatic approach to education, which dates back to Dewey (1929), posits a transactional realism, one in which reality only reveals itself as a result of the activities of the organism, and thus the focus should be on the "interactions between the living human organism and its environment" (Biesta & Burbules, 2003, p.10). Instead of separating mind from matter (real world), Dewey's pragmatism incorporates both of them into one entity conceptualising nature itself as "a moving whole of interacting parts"

(Dewey, 1929, p.232). Dewey did not want to identify his pragmatism with any of the two extremes (i.e. idealism vs. realism).

Thus, knowledge, from a pragmatic standpoint, is viewed as being collaboratively shaped by researchers and practitioners, and consequently, educational research should be viewed as a collaborative process aiming at simultaneously improving both theory and practice (Biesta & Burbules, 2003; Reeves, 2006).

Thus, pragmatism, as Tashakkori and Teddlie (1998) argue, has emerged as a grounding philosophy or approach to resolve the traditional conflict between two research paradigms (positivist and interpretivist/constructivist) in education and social science. More specifically, pragmatism, for me, contributes to this compromise on both the epistemological and methodological levels.

A clear link between pragmatism and DBR has been established. For example, Confrey (2006) states that pragmatism is more related to DBR than to experimental research as it does not place theory on a shelf to be used only as a guide to pristine experimentalism. Instead, it places it squarely into the real world of action and experience, and thus, it engages with complexity rather than striving to artificially reduce it. Similarly, the account given on the principles of pragmatism as an action-oriented approach guiding educational research implies a straightforward connection with DBR: (1) the immediate reality of solving educational problems should be the focus of educational research; (2) educational settings and problems can be studied using any method that accurately describes and solves problems; (3) educational research should strive to find ways to make education better; (4) researchers should collaborate with participants to fully understand what works; and (5) theories are useful tools in helping to improve education.

### **DBR as an emerging paradigm in educational research**

In this section, I will elaborate more on DBR as an emerging paradigm. This involves shedding some light on its background, characteristics, and the criticism directed to it as well as the challenges associated with employing it in research studies.

DBR is the outcome of endeavours to forge a paradigm and/or methodology in education, which sits between the traditional randomised trials of experimental research that rely on controlling variables, and the qualitative approaches that provide deeper accounts (Kelly, 2007). It came to the fore as a new pragmatic approach taking many forms in various educational settings to bridge the gap between theory and practice, and thus improve educational practices and resolve problems attached to them (Cobb, et al, 2003).

Some factors stimulated the establishment of a new paradigm in educational research; one factor is the growing need to develop 'usable knowledge' that connects the researchers' theoretical frameworks and understandings with the local context of practice. Increasingly, experts call for research to be judged not only on the merits of disciplined quality, but also on the adoption and impact in practice (DBRC, 2003); otherwise, educational research will not involve any direct pragmatic benefits or implications for the contexts in which teaching/learning takes place. Another factor relates to the motivation to linking educational research to the problems and/or issues of everyday practice and classroom environments with their richness, messiness, and complexity (Brown, 1992). A third factor involves meeting the need to develop

a design science of education, and the need for approaches to studying learning phenomena in the real world rather than the laboratory (Collins, Joseph, & Bielaczyc, 2004).

Collins et al. (2004) identify several needs central to the study of learning that DBR intends to address, and which rationalise establishing it as a new paradigm: (1) to address theoretical questions about the nature of learning in context; (2) to use approaches to studying the learning phenomena in the real world situations rather than the laboratory; (3) to go beyond narrow measures of learning; and (4) to derive research findings from formative evaluation.

DBR has been originally known in educational research as 'design experiments' (Brown, 1992), though the former term, as Sandoval and Bell (2004) suggest, is more comprehensive and obvious than the latter, which denotes a specific form of controlled experimentation that does not capture the breadth of the approach.

DBRC (2003) characterises DBR as a research paradigm which blends empirical research in education with the theory-driven design of learning environments. It is an emerging approach for understanding how, when, and why educational innovations work in practice, inquiring into the nature of learning in a complex system to refine generative or predictive theories of learning.

A persistent question is: why DBR now? According to Van den Akker, Gravemeijer, McKenney, and Nieveen (2006), there are three main motives for using DBR: (1) the desire to increase the relevance of research for educational policy and practice; (2) the goal of developing empirically-grounded theories through combined study of both the process of learning and the means supporting it; and (3) the aspiration of increasing the robustness of design practice.

There are many characteristics that distinguish DBR making it a unique approach. On a broad methodological level, DBR eliminates the boundary between design and research by making the design process an opportunity to advance the researchers' understanding of teaching, learning, and the educational systems (Abdallah, 2011b).

Van den Akker, et al. (2006) characterise DBR as being: (1) 'interventionist', since the research aims at designing interventions in real-world settings; (2) 'iterative', since it incorporates cycles of analysis, design/development, evaluation, and revision; (3) 'collaborative', since it involves active participation of practitioners in the various research stages and activities; (4) 'process-oriented', since the focus is on understanding and/or improving interventions, and hence, a black-box model of input–output measurement is avoided; (5) 'utility-oriented', since the merit of a design is measured in part by its practicality for users in real contexts; and (6) 'theory-driven', since the design is, partly at least, based on a conceptual framework and theoretical propositions, whilst the systematic evaluation of consecutive prototypes of the intervention contributes to theory building.

In the same vein, Bowler and Large (2008) characterise DBR as: (1) 'multi-purposed', as it serves theory, design, and practice; (2) 'contextual', in the sense that research is conducted in its real learning setting where researchers, practitioners, and users are part of the context; (3) 'flexible', as it uses a combination of (qualitative and quantitative) mixed methods as the need demands, and this flexibility is a strength in it; and (4) 'producing a working artefact' in the form of a curriculum, programme, learning environment, or a piece of software.

DBR involves using different and mixed methods in the processes of data collection and the evaluation and refinement of the design which help to increase the "objectivity, validity, credibility and applicability" of the findings. Some DBR authors suggest mixing different methods or the triangulation of data sources and respondents based on the fact that "the effectiveness of triangulation rests on the premise that the weaknesses in each single data resource will be compensated by the counterbalancing strength of another" (Abdallah, 2011b).

### **Criticism and challenges**

There are a number of criticisms and challenges regarding DBR, since it is an emerging paradigm that has been recently adopted with enthusiasm. A significant area of criticism relates to the fact that DBR, compared with other research approaches and methodologies, can be 'over-methodologised', with excessive amounts of collected data and, subsequently, much required analysis (Brown, 1992). Brown elaborates on the different types and means of data collection (e.g., students' scripts, observations, records of students' portfolios, and extensive audio and video tapes) which also lead to another concern related to selection bias.

Being 'under-conceptualised' is another point (DiSessa & Cobb, 2004; Dede, 2005). According to Dede (2005), part of this shortfall may be attributed to the fact that the skills of creative designers and the attributes of rigorous scholars have limited overlap. Effective design-based research groups usually try to strike a balance between 'whatever works' for innovation and controlled, principled variations. People fascinated by artefacts often start with a predetermined solution and seek educational problems to which it can be applied, which ultimately leads to under-conceptualised research. However, Dede (2005) contends that under-conceptualising and over-methodologising are not intrinsic to DBR, as some design studies result in valuable findings using elegant collection and analysis strategies.

A third point relates to the 'difficulty of making generalisations' among participants. According to O'Donnell (2004), this may be because of the complexity involved in implementation. In addition, generalisation in DBR may be difficult due to the inability to control many variables in complex settings and to analyse in full the large amount of data collected before the next cycle.

In relation to the areas of criticism discussed above, there are a number of challenges for using DBR in this study. These challenges are addressed below with special focus on how to manage them in this particular context.

First, the *challenge of context and time span* was a significant problem. Herrington et al. (2007) argue that DBR is avoided by doctoral students who are expected to complete their degrees in 4-5 years, but, in a sense, they can make some adjustments. Initially I was reluctant to adopt DBR, especially because this PhD project should not exceed 4 years during which the field study in Egypt should be conducted within 3 months. To resolve this, I had to be flexible by decomposing the big research problem into specific tangible components (e.g., focussing on some new literacies based on the Web as they related to the English language skills) that could be tackled within this time span. Further research might be conducted to take my conclusions and design principles as a point of departure instead of re-inventing the wheel.

Second, the *challenge of validity and credibility* is persistent in DBR as it is a flexible methodology that uses both qualitative and quantitative methods for processing data without any controlled experimentation. Addressing this challenge, Bowel and Large (2008) contend that the contextual nature of DBR is the key answer. Although theory developed within a



controlled, laboratory environment may lay claim to external validity, it may lack ecological validity and, thus, makes no sense in the real world. The strength of DBR is that it happens in real context, and its resulting designs are able to meet certain local needs and be useful to practitioners, and hence, the validity issue can be addressed. Further, the practice of using multiple methods in DBR builds a body of evidence that may enhance and confirm the credibility of findings (Abdallah, 2011b).

It is not possible in most educational contexts to employ the so-called 'gold standard' experiments to the educational processes as is the case with randomised trials. Instead, design-based researchers utilise multiple, mixed methods to build up a body of evidence that supports the theoretical principles underlying a specific innovation and refines the innovation itself in context. Therefore, a useful practice for addressing any concerns related to reliability, validity, and credibility associated with DBR is to use triangulation as a research tactic which scholars perceive as a powerful way of demonstrating concurrent validity (Abdallah, 2011b).

Third, the *challenge of adaptability* is relevant. DBR is a flexible research design that is open to modifications and adaptations to be made as the context and research conditions require (Plomp, 2009). Further, design researchers should adapt themselves to other roles to play beside their fundamental role as researchers (e.g., the additional roles of designers, advisors, and facilitators) without losing sight of their primary role (Van den Akker et al., 2006; McKenney et al., 2006). This may complicate the process, but the good researcher knows how to balance these roles by realising when a role should be more dominant than another in a certain stage.

Last, the *challenge of rigour*. Some authors express some concerns related to rigour when DBR is conducted since it is still an emerging paradigm, which has not yet established its peculiar standards and criteria. Comparing it with experimental research that has long-established rigour and criteria. Using DBR raises many questions related to rigour such as how to ensure that we have adequately characterised an intervention that we did not entirely control; and how to generalise outcomes and results to other contexts. However, he contends that DBR can be more rigorous in certain ways; in particular, it is strong at helping with connecting interventions to outcomes and can lead to better alignment between theory, treatments, and measurement than experimental research in complex realistic settings like the classroom (Abdallah, 2011b).

## **5. Research framework: The three-phase DBR design**

After introducing DBR as the main paradigm utilised, I introduce the research framework of the study which is based on a three-phase DBR design derived from Nieveen . (2009) and Plomp (2009). A diagram was devised (see Figure 1) to illustrate this framework through outlining the research methods and procedures followed in the three phases of this design study to accomplish my objectives.

I present here the main research framework, which delineates the organisation of the research methods and procedures under the DBR umbrella (see Figure 1).

Reeves (2006) depicts the DBR approach as a process which starts from the identification and analysis of problems by researchers and practitioners in collaboration; and then goes through the development of prototyping solutions informed by theories, existing design principles, and technological innovations; then involves iterative cycles of testing and refinement of solutions in practice; and finally, results in reflection to produce design principles and enhance solution implementation in practice.

Drawing on Nieveen et al. (2009), and Plomp (2009), the procedures and steps followed for conducting the study fall under three main research phases (see Figure 1 below):

1. The *preliminary phase*, in which the procedures of needs and content analysis, review of literature, and development of a conceptual or theoretical framework for the study are conducted. As indicated in Figure 1 below, this stage involves identifying and formulating the problem of the study through: online interactions with participants; a review of relevant empirical studies to identify the gap; and real interactions with both EFL student teachers and their educators (a long-term process that started already a few years ago). It also involves doing a comprehensive review of literature that serves two main purposes: (1) clarifying the key research terms (e.g., Web-based new literacies, EFL teacher education, and curriculum design); and (2) providing a theoretical foundation for the concurrent documentary analysis process. Finally, it involves collecting preliminary empirical data at this stage through: (1) a documentary analysis process that leads to a list of Web-based new literacies; (2) semi-structured interviews (conducted online with 19 EFL student teachers and educators at AUCOE) that leads to some Web-based facilities. Both products are necessary for informing the preliminary design framework that should guide the next stage of this design study (i.e. the prototyping phase). The arrows in Figure 1 below illustrate such relationships, and thus provide a conceptual diagram of how the process goes.
2. The *prototyping phase* (the iterative design phase), which consists of iterations, each being a micro-cycle of research with formative evaluation as the most important research activity aimed at improving and refining the intervention. As Figure 1 shows, this phase is guided by a preliminary design framework concluded in the preliminary phase. This is followed by a screening questionnaire administered for identifying a purposive sample to use in the prototyping phase. Each research cycle (as the arrows in Figure 1 indicate) leads to a revised framework based on results and which guides the next cycle, until a final design framework is reached.
3. The *assessment/reflective phase*, which concludes whether the solution or intervention meets the pre-determined specifications, resulting in recommendations for improving the intervention. In this phase, a final design framework is reached throughout a comprehensive assessment of the 2 iterations or research cycles conducted in the previous stage. This framework (as the arrows indicate) involves implications for EFL curriculum design, along with contributions to theory, practice, and methodology.

It is worth mentioning that throughout phases 1 and 2, the instruments and techniques used for data collection are developed in the light of the needs of the research and the specific purposes of the study. Both quantitative (e.g., online questionnaire) and qualitative (e.g., semi-structured interviews) data collection methods are used. Since the aim of this initial stage is to set the scene for the whole research project, it mainly involves direct interactions with the Egyptian context itself to formulate the necessary background data.

This background data is obtained through: (1) a short-term pilot study that involves some semi-structured interviews with both EFL student teachers and their educators. The main goal here is to obtain reflective accounts of the real problem in context and the realistic literacy needs of the target student teachers; (2) a documentary analysis of some online texts and accounts written by specialists in the field. The goal guiding this analysis is to formulate a comprehensive list of

those Web-based new literacies deemed important to EFL student teachers in the target context. Sometimes, some English language specialists and educators known for an interest in the Web and language learning were approached through e-mail to provide their accounts in the form of an essay or a list to be analysed later on. These accounts were useful throughout the documentary analysis process as they represented practical voices from the field. The documentary analysis process resulted in the formulation of a preliminary list of Web-based new literacies in which 73 items were suggested under four main categories which included other sub-categories:

1. Membership in online communities;
2. Composing and writing online;
3. Knowledge construction and idea sharing; and
4. Employing the Web as an online library and a main language-learning resource.

As a confirmatory procedure, these categories including the 73 items composing them were administered through an online questionnaire to Egyptian EFL student teachers and their educators to check the extent to which they were relevant and needed in Egypt; (3) semi-structured interviews were conducted online with 19 participants to identify which Web-based facilities (e.g., e-mail, chat, search engines, Facebook, and Wikis) are really needed in EFL teacher training, why they are needed, and how they can be employed for effective language-learning purposes.

As far as the next stage (i.e. the prototyping phase) is concerned, it is important to mention that the 36 participants were selected from among the target student teachers based on a screening questionnaire that determined which student teachers possessed the minimum level of knowledge and skills required for the interventions. Then, the first cycle (i.e. the CoP design) was conducted online for two months (while I was in England) with Egyptian participants, while the second cycle was conducted completely face-to-face with participants for three months.

I should admit that the Internet (as a research tool and means of communication, not just as a research topic) facilitated the process of data collection throughout the preliminary stage: the new literacies questionnaire was administered online, and the semi-structured interviews were conducted online by means of e-mail communication and chat. Otherwise, I should have travelled back to Egypt many times to administer those tools face-to-face to the target participants.

Moreover, this division into three phases was intended for organisational purposes. In reality, the phases were connected together as sometimes, I needed to build upon the empirical data in the preliminary phase to construct an initial design framework that would inform the procedures in the next phase. Similarly, the two cycles in the prototyping phase (i.e. both the CoP design and the Blended Learning design) were related. I needed to visit the first cycle sometimes to double-check something or notice something that could have helped with the next cycle.

In the preliminary phase, some methods and procedures of data collection and analysis were followed. After reviewing literature to provide a theoretical background, empirical data were needed to characterise the target context by identifying the literacy needs of the Egyptian EFL student teachers, with specific reference to AUCOE. The identification of these needs contributed to answering the first two research questions. Thus, a review of literature was conducted to inform a concurrent documentary analysis process with the aim of compiling

a Web-based new literacies list. The generated list in turn was administered through an online questionnaire to some Egyptian participants (n=50), consisting of both EFL student teachers and educators, with the aim of contextualising it within the target context. The fifty participants were identified online, and thus were the ones who were familiar with the topic, and also able to use the Internet and handle the online questionnaire properly.

To answer the second research question, semi-structured interviews were conducted to explore the Web-based facilities useful to them from the perspectives of both EFL student teachers and their educators. This list, along with the interview data, was used as resources to inform a preliminary design framework guiding the first iteration in the subsequent prototyping phase. In addition, to identify based on certain criteria the required participants throughout a purposive sampling process, a screening questionnaire was prepared and administered face-to-face to the whole group of senior EFL student teachers at AUCOE as a procedure necessary for the prototyping phase.

Within the prototyping phase, which consisted of two iterations, the aim of the first iteration was to investigate through online interventional tasks the possibility of expanding EFL student teachers' language-related literacy practices while working online as a community. The interventional tasks were intended to gradually expose participants to some Web-based new literacies not familiar within their education programme. Throughout working as a community, participants started to develop many literacy skills.

Through this online intervention, some interventional tasks were administered online through e-mail communication on a daily basis for a two-month period. Those tasks included: (1) posting something on the group Blog; (2) commenting on a post made; (3) reading an article online; (4) sending feedback; (5) searching for something online; and (6) using a new online tool. In response to the tasks, participants contributed through e-mails, Blog posts, and feedback reports. These contributions were qualitatively analysed (by means of thematic analysis supported with NVivo software) to inform the process of evaluating the intervention by establishing some conclusions in the form of lessons learned to be cycled back into the next iteration. This should help with establishing a more comprehensive framework to guide the next iteration.

However, some weaknesses were observed that helped me to improve the design such as: (1) using the online alone was not effective as participants needed more direct interactions; (2) more training on using some online facilities like Wikis was needed; (3) there was a need for modifying the design framework to involve a blended socio-constructivist learning theory; and (4) more links with other academic courses studied by student teachers were needed.

In the second iteration of this design study, based on lessons learned from the first iteration as well as some empirical data from the preliminary stage, the preliminary framework that informed the first iteration was refined into a more comprehensive and detailed one to address the weaknesses which were observed in the previous CoP design. The second iteration was displayed as a micro-cycle of research that employed a blended learning design that involved a socio-constructivist theory of language learning facilitated by the web to resolve the weaknesses/shortcomings of the first iteration.

Based on the final results obtained from the second iteration, a final revised design framework was suggested. It included some implications for curriculum design in the target context. A final design framework was generated based on the results obtained from the two iterations, and thus the third and fourth questions of the study were answered.

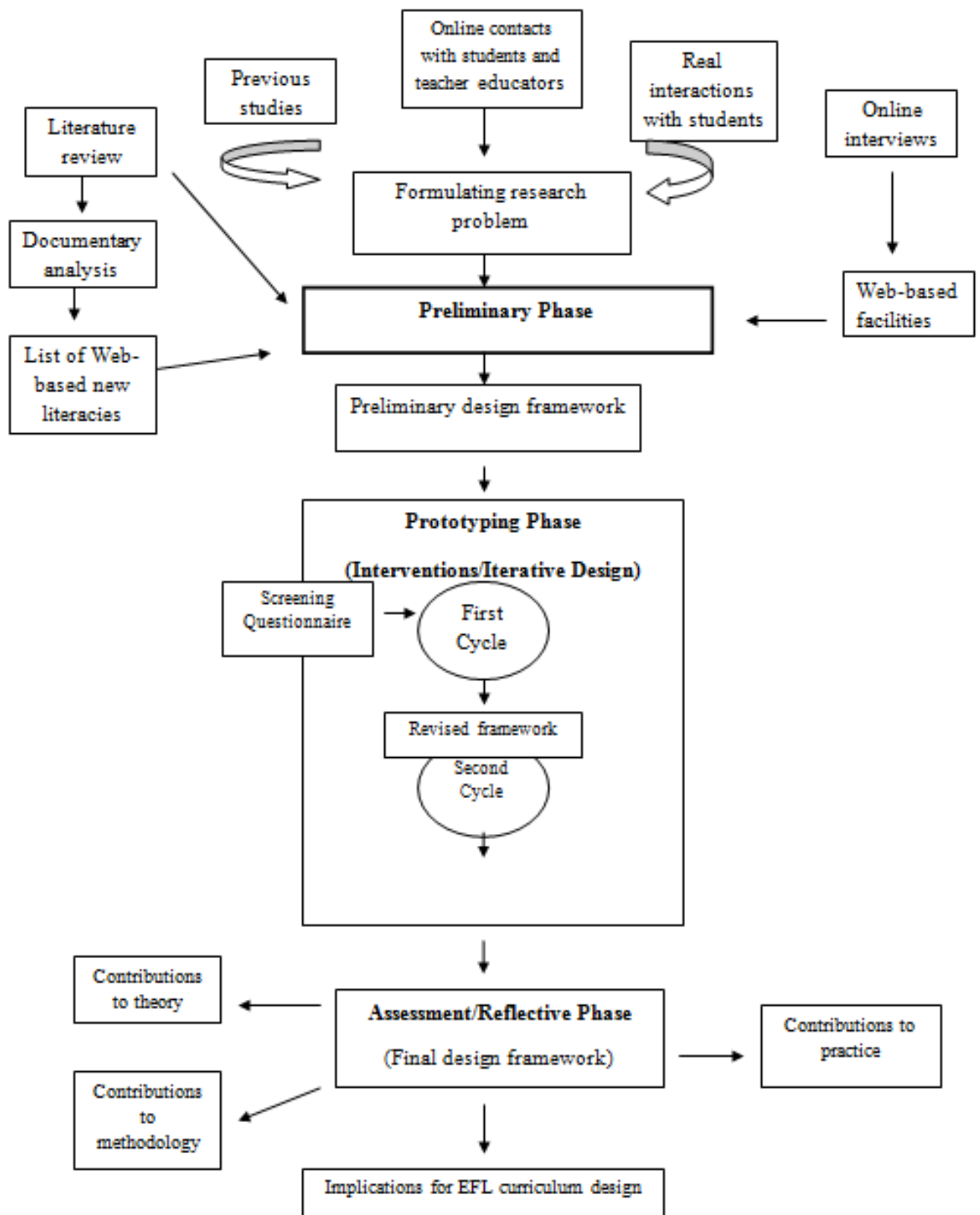


Figure 1: Research framework

The suggested design principles composing the final design framework were organised around five focal points: (1) learning design, (2) language learning theory, (3) course administration, (4) learning models and activities, and (5) Web-based facilities as online spaces for language learning and practice. These topics were intended only to classify these principles, not to create boundaries between them. Examples of those principles are:

- A blended learning design should be employed as a flexible solution for integrating Web-based new literacies into the target Egyptian context of AUCEOE with the aim of expanding EFL student teachers' language-related literacy practices;
- Under the blended learning design, flexible shifts should be made during the lessons between face-to-face interactions and online interactions;
- Technical training on basic computer and Internet skills is an essential prerequisite for EFL student teachers to avoid and/or minimise technical problems that might occur while learning under the blended mode;
- While designing any courses for EFL student teachers that aim at involving them in new language-related literacy practices mediated by the Web, links should be made with other academic English language courses so that the usefulness and practicality of the course can be realised;
- Under the umbrella of blended learning, a dialogic, socio-constructivist pedagogy should be employed as an ELL approach that guides the process of expanding EFL student teachers' language-related literacy practices at AUCEOE;
- EFL student teachers need to be gradually introduced to the dialogic, socio-constructivist pedagogy that is new to them so as to change their competitive learning attitudes and get used to learning together and supporting each other;
- Under a socio-constructivist pedagogy, the Web should be viewed from an 'affordances' perspective that stresses its dialogic, socio-cultural nature as well as its mediational function in literacy development and language learning;
- English should be the medium of instruction and the language of communication among student teachers both face-to-face and online, if language proficiency is the target;
- The lessons should reflect a gradual transition from controlled activities to collaborative/cooperative activities that involve pair work and group work, ending with some online independent tasks.
- A class Wiki is needed as an online platform for delivering the course, and as an online space where student teachers can practise online collaborative writing in English.

As far as the curriculum design orientation of the study is concerned, the two main curricular products resulting from the study are: (1) tasks (resulting from the first cycle), and (2) blended course (resulting from the second cycle). The blended course in turn involves three minor curricular products: a class Wiki, a class Blog, and an e-group. Student teachers' interactions with (and use of) those curricular products should eventually lead to professional development.

## Key source

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Based on his MA and TOEFL scores, he was nominated by the Egyptian Scholarship Department to get a fully-sponsored governmental scholarship to pursue his PhD degree at the University of Exeter, England, UK, and in 2011, he got his PhD. Dr Abdallah is mainly interested in the relationship between new

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## Empirical Development of a Model for Implementing Online Learning at Academic Institutions

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# 44. Empirical development of a model for implementing online learning at academic institutions

Sangeetha Gopalakrishnan

## Abstract

*This chapter presents an example of Educational Design Research (EDR) from the domain of online learning (OL) in the higher education sector in the United States. The vast majority of higher education institutions in the U.S. have substantially grown their online enrollment in the last decade. Many universities and colleges in the U.S. are delivering courses and programs online in addition to their traditional offerings which are on-campus and face-to-face. Moving courses and entire programs online is a complex, multi-faceted undertaking which requires a comprehensive approach. A significant problem encountered by academic institutions in the U.S. establishing large-scale online initiatives is the paucity of holistic frameworks to guide the migration to OL. The proposed intervention for this practical challenge in online education is the empirical development of a model for OL implementation. As part of a qualitative study undertaken to address this problem the online efforts of several institutions successful in OL in the U.S. and individuals responsible for leading online initiatives at these institutions were examined. Best practices and leadership strategies for OL implementation were first identified and then a model for establishing online programs that encapsulated these practices and strategies was developed. A framework of organizational change was used to guide this investigation. This chapter describes the initial stages of this design research, namely the preliminary research and the development of a prototype of the intervention.*

## Empirical development of a model for implementing online learning at academic institutions

This chapter presents a case study of Educational Design Research (EDR) from the field of online learning (OL) in the higher education sector in the United States. In addition to delivering courses and programs in the traditional manner, i.e. on-campus and in the face-to-face format, many academic institutions in the U.S. are interested in also offering them fully online.

A significant problem confronting higher education institutions looking to establish large-scale OL initiatives is the paucity of comprehensive models for guiding the migration of course offerings online. A qualitative research study was conducted to develop an intervention, namely a model for OL implementation, which would address this problem. This chapter describes the problem in context, related literature and the conceptual framework for the study, and the design and development of a prototype of the model.

## 1. Introduction to the problem

In the last decade online education has experienced an explosive growth in the United States. Many higher education institutions in the U.S. are seeking to establish large-scale online courses and programs, and are interested in knowing how to achieve sustained success in their online initiatives. Various studies describe benchmarks and guidelines for achieving quality in distance education (DE), and factors that influence success in online education. The literature

also suggests that the implementation of OL at academic institutions is a complex undertaking requiring a holistic, rather than piecemeal, approach. However, the problem confronting institutional leaders and planners is that few comprehensive frameworks for the institution-wide migration of programs online exist.

### **Desired outcomes of the research**

The objective in this research study was to address the lack of holistic approaches for setting up large-scale online initiatives at academic institutions. This chapter describes the preliminary stages of this EDR. The purpose of the investigation described in this chapter was to first identify best practices and leadership strategies for moving to OL and then to develop a model that encapsulated these practices and strategies.

### **Research questions**

The research questions that guided this study pertain to identifying best practices and leadership strategies for successful OL implementation in higher education and developing a model that encapsulates these practices and strategies. (For a more detailed description of the research questions that guided this investigation see Gopalakrishnan, 2011.)

### **Educational design research as a research approach**

Primarily EDR is about finding solutions to problems in education and developing theoretical approaches for creating such solutions (Plomp, 2009). The “Starting point for design research”, according to Plomp (2009), “are educational problems for which no or only a few validated principles ... are available to structure and support the design and development activities” (p. 13). The successful implementation of large-scale online initiatives at academic institutions is as such a complex undertaking for which few, if any, validated comprehensive approaches exist. In EDR the primary research function is to design and develop an intervention (Plomp, 2009). The investigation described in this chapter was aimed at the empirical development of a model that when adopted would lead to the successful implementation of online education at an academic institution.

### **EDR approach applied**

Plomp (2009) describes the process of EDR as follows: “Informed by prior research and review of relevant literature, researchers in collaboration with practitioners design and develop workable and effective interventions” (p. 13). He notes that the final versions of these interventions are created in an iterative manner after testing prototypes in the intended settings and revising them. Finally, in EDR after introspectively examining the research process, researchers also create design principles for developing similar interventions. According to him, design research typically includes the following stages: preliminary research, prototyping, and assessment. This chapter reports on the first two stages of a larger study aimed at developing a model for implementing successful online initiatives in higher education. As is typical for the initial stages of an EDR project, in this study a prototype for an OL implementation model was developed based on a review of the literature and the experiences of practitioners in establishing OL in higher education institutions. This chapter describes the preliminary research conducted and the development of the first prototype of the OL implementation model.

In a prototyping approach, according to Nieveen (2009), empirical data are needed to evaluate the merits of both the tentative intervention and the design principles. Nieveen (2009) presents four criteria for judging the quality of interventions: relevance, consistency, practicality, and effectiveness. “At the end of a design research project”, she asserts, “the intervention should

suffice all of these criteria” (p. 93). She clarifies that typically each iteration in the development of a prototypical intervention focuses only on one or two of these criteria. In the early stages of development of a prototype, the emphasis is on the relevance and consistency of the intervention, according to her. As the development progresses the focus shifts to assessing the expected practicality of the intervention. With each development stage and as the intervention becomes full-fledged, assessing its actual practicality and effectiveness become key considerations. Since the research reported in this chapter is in the early stages of prototype development, this case study will focus on the relevance of the OL implementation model (i.e. establishing the need for the model and its design based on a literature review), its consistency (ensuring that it is logically designed), its expected practicality (whether the model can be adopted in different settings), and its expected effectiveness (whether using the model is expected to lead to success in OL).

## **2. Literature review and conceptual framework of study**

The problem studied in this case study has two major aspects, namely establishing online programs and implementing innovation and change in academia. Each aspect of the problem is discussed next.

Online education in the United States has experienced phenomenal growth in all sectors of higher education in the last decade (Allen & Seaman, 2013). Academic institutions in the U.S. deliver courses and programs online in addition to offering them on-campus and face-to-face for a variety of reasons such as, increasing student access to education (Allen & Seaman, 2007; Miller & Schiffman, 2006; Parsad & Lewis, 2008), meeting student needs for flexibility in schedules (Parsad & Lewis, 2008), enhancing the quality of teaching for existing on-campus students (Miller & Schiffman, 2006), expanding the traditional geographic reach of the institution (Allen & Seaman, 2007) and increasing student enrollment (Parsad & Lewis, 2008). Many in academia regard the online delivery of instruction as a legitimate and effective way for students to learn. Numerous studies have shown that learning online can be as effective as learning through traditional face-to-face instruction (Means, Toyama, Murphy, Bakia, & Jones, 2010). An increasing number of academic leaders believe in the efficacy of online education (Allen & Seaman, 2013). About seventy percent of all higher education institutions regard OL to be of strategic importance to them (Allen & Seaman, 2013), particularly in the current economic downturn (Betts, Hartman, & Oxholm, 2009). Given the promise of OL, many in higher education today are interested in knowing how to establish successful online initiatives.

Despite the potential of online education institutional leaders and planners face a variety of obstacles in implementing online initiatives (Allen & Seaman, 2007; Hawkins, 1999; Levine & Sun, 2002; Moloney & Oakley, 2006/2010). Of all the factors impeding the move to online education, faculty resistance is cited as the most significant barrier (Allen & Seaman, 2007). In addition, numerous other institutional issues arise when instruction is delivered fully online. These issues include faculty workload, incentives and support structures, business models, entrepreneurial administrative structures, technology infrastructure, quality assurance, cost-effectiveness, program expansion and growth management, market survey and program marketing, institutional policies on intellectual property, student support systems and retention, need for more discipline on the part of online students, and acceptance of online degrees by employers (Allen & Seaman, 2007, 2013; Hawkins, 1999; Levine & Sun, 2002; Lynch, 2005; Miller & Schiffman, 2006; Moloney & Oakley, 2006/2010; Otte & Benke, 2006; Sener, 2006). A review of the literature strongly suggests that moving to OL is not merely a technological issue but a multifaceted undertaking. Planned and holistic approaches that address the barriers and

the institutional issues are needed to orchestrate the migration to and achieve success in the online environment (Hawkins, 1999; Levine & Sun, 2002; Lucas, 2000; Otte & Benke, 2006).

Several researchers describe guidelines for achieving quality in distance education (DE) (Phipps & Merisotis, 2000; WCET, 2002) and factors that influence the success of online initiatives (Abel, 2005; Bates, 2000; Moloney & Oakley, 2006/2010). These DE quality guidelines and OL success factors can be placed into the broad categories of:

- Institutional commitment and support
- Faculty support
- Student support
- Course development support
- Technology support; and
- Evaluation and assessment.

However, there is a need to determine how to integrate these individual quality and success characteristics for OL into a holistic implementation approach. A significant problem for those interested in leading large-scale online initiatives at educational institutions is that few comprehensive approaches or frameworks for setting up institution-wide online programs exist.

The second major aspect of the problem that was examined in this investigation relates to implementing innovation and change in academia. When instruction is delivered fully online it has broad and deep repercussions for the institution. Some researchers call for a major restructuring of the entire academic environment for success in online education (Bates, 2000; Beaudoin, 2002; Watkins & Kaufman, 2003). The institution-wide implementation of online programs may be tantamount to leading organizational change. However, only a few scholars view the large-scale migration of programs online as a change initiative (Keaster, 2005; Owen & Demb, 2004). Experts in the field of organizational development outline various procedures and models for effecting change in business organizations. Perhaps, practices and strategies deployed to bring about organizational transformation in business settings may be useful in leading the move to OL at academic institutions. The steps described in four prominent change management models, namely, Kotter's Eight-Stage Process (Kotter, 1996), Cummings and Worley Model (Cummings & Worley, 2005), Whetten and Cameron Model (Whetten & Cameron, 2005), and Pascale and Sternin's Positive Deviance Model (Pascale & Sternin, 2005) may be useful for setting up online initiatives at educational institutions. The common elements of these four models may be combined to create a framework for examining the migration of academic institutions to online education.

Leadership is touted as critically important in bringing about any kind of organizational change (Kotter, 1996). Leadership is also emphasized as crucial when an educational technology innovation, particularly online education, is implemented at academic institutions (Bates, 2000; Keaster, 2005; Miller & Schiffman, 2006). However, there is a dearth of literature on the role of leadership in implementing online initiatives (Beaudoin, 2002). Various publications discuss the role of a change agent in the diffusion of innovations (Ely, 1999; Otte & Benke, 2006; Rogers, 2003). The literature suggests that institutional leaders (Abel, 2005; Green, 1997; Otte & Benke, 2006) and change agents can play significant roles in the move to online programs. Leadership for academic change brought about by educational technology and OL implementation should be forthcoming at multiple levels and places within the institution (Bates, 2000; Beaudoin, 2002; Otte & Benke, 2006).



In effecting any kind of academic change the culture and characteristics of academia should be considered. Characteristics of academic institutions such as shared governance, faculty autonomy, and decentralized power structure are particularly influential when it comes to effecting change (Bates, 2000; Eaton, 2000; Jaffee, 1998; Miller & Schiffman, 2006). Different approaches to bringing about academic change are presented in the literature. An entirely administrator-driven approach to establishing online programs is untenable in the academic setting (Beaudoin, 2002; Otte & Benke, 2006). Faculty-led initiatives are most compatible with academic culture; however, an entirely faculty-led initiative is problematic (Bates, 2000; Beaudoin, 2002). The literature seems to call for a combination of administrator-driven and faculty-led initiatives (Green, 1997; Twigg, 2000; Wickersham & McElhany, 2010).

In reviewing the four change management models closely it is evident that there are steps and procedures that are common and core to any organizational transformation. A theoretical framework for studying OL implementation can be derived by combining and sequencing the common core elements of these four models as follows:

1. Creating a vision for change
2. Communicating the vision for change
3. Motivating change
4. Creating a coalition of support for the change
5. Managing the transition, and
6. Sustaining the change.

### **3. Research methodology**

This chapter reports on the early stages of a complex EDR project which involves the development of a model for success in OL implementation at academic institutions. During this preliminary phase of the design research, based on a literature review and practitioners' experiences, a prototype of a model for OL implementation in higher education was developed. The research methodology presented in this section pertains to the preliminary phase and describes the research participants and the methodology for designing and developing a prototype of the OL implementation model.

#### **Participants**

The participants in this study included both academic institutions and individuals. Eleven academic institutions with the reputation for being successful in online education and ten individuals with the lead responsibility for setting up large-scale online initiatives at these institutions participated in this study. Institutions were located in different parts of the U.S. Three of the participating institutions were university systems. The other eight participating institutions were individual universities, of which four were classified at the research level and four at the master's level as per the Carnegie classifications. The institutions were all under public control and ten of them had tenure systems for faculty. Participating institutions varied in size, from 5000 to 196,000 students, and in online enrollments, from 3,368 to about 196,000. The majority of the participating institutions had established their first online program between the mid and late 1990s and had been providing OL for at least 10 - 15 years. Most of the participating institutions also had a history of institutional involvement with DE. Furthermore, most of them had dedicated DE and or OL units.

The ten individuals that participated in this research, namely the OL leaders, held lead responsibility for establishing institution-wide online programs at the institutions selected. One of the OL leaders was associated with two of the participating institutions. Most of them headed

DE or OL units at their institutions. They were situated high in the organization hierarchy and reported directly to university or system presidents, provosts and vice-chancellors. The majority of them had a long institutional affiliation and had also led OL implementation for at least a decade. They all had a doctorate and more than 10 years of DE experience.

### **Research design**

This EDR was designed to be a qualitative study and consisted of two significant data analysis phases. In the first phase best practices and leadership strategies for establishing successful online initiatives were identified. In the second phase a model encapsulating these practices and strategies was developed.

### **Data collection**

Data were primarily collected through in-depth one-on-one interviews with the OL leaders. The framework derived from the four organizational change models structured the interviews. The interview questions were mainly aimed at gathering information about the practices and strategies that led to the successful implementation of OL at the participating institutions (see Gopalakrishnan, 2011, p. 370 for a description of the interview instrument). Extant data about the institutions and their online offerings and demographic information about the OL leaders were also gathered from institutional websites and online sources. The interviews were held via videoconferencing and over the phone and most of them lasted about an hour.

### **Data analysis**

The primary data that were analyzed were the interviews with the OL leaders. Interview transcripts were searched for practices and strategies that related to OL implementation. Patterns and themes were identified and frequencies noted. Data were organized and coded using a Microsoft Excel spreadsheet.

### **Pilot study**

To ascertain the feasibility of the proposed investigation and any potential flaws in the research methodology a pilot study was conducted with one institution and one individual meeting the selection criteria. Based on the pilot participant's feedback no major revisions were made to the data collection procedures after this initial try-out. The data analysis procedures were tested by analyzing data collected from the pilot interview. An attempt was also made to develop a draft version of the model based on this pilot data analysis. Based on these try-outs some refinements were made to the data collection, analysis, and synthesis procedures.

### **Model development**

Once the best practices and leadership strategies were identified and their frequencies noted, they were grouped into major topics. These categories formed the basis for the Leadership and Change Model for OL implementation presented in the next section.

## **4. Results**

This section describes the outcome of the initial phases of this design research, namely the prototype of the model for establishing large-scale online initiatives at academic institutions.

### **Leadership and Change Model for OL Implementation**

The Leadership and Change Model for OL Implementation has three *leadership components* and nine major *phases*. Most of the phases are further constituted by *elements*. *Best practices and leadership strategies* are mapped to these elements.

The three leadership components are:

1. Institutional leadership
2. Faculty leadership, and
3. OL leader.

Institutional leadership should drive the move to online education and provide strong support for it. At the same time faculty should also propel the offering of online courses and programs. There should be a principal change agent, an OL leader, orchestrating the migration to the online environment.

Next, an overview of the nine phases of the model is provided.

1. Create a vision and goals for OL - As a first step a vision for the institutional move to online education and goals for what is to be accomplished with such a move should be created.
2. Draft a strategic plan - As part of a strategic planning process crucial institutional issues that arise when instruction is delivered fully online should be identified and key questions should be raised.
3. Motivate the move to OL - In this phase faculty, administrators, students, and other stakeholders should be motivated to migrate to OL.
4. Communicate vision and goals for OL - The institutional vision and goals for OL should be communicated to the academic community.
5. Develop political support for OL - Political support for the adoption of OL should be garnered from faculty, administrators, students and other stakeholders.
6. Manage the transition to OL - This phase involves orchestrating the actual migration of courses and programs to the online environment.
7. Measure outcomes of OL - Various outcomes of the online enterprise should be measured to see if the goals set for the institutional move to OL are being realized.
8. Ensure quality of OL - The quality of different aspects of the online initiative must be ensured.
9. Sustain the move to OL - Once some initial momentum in setting up online programs has been gained, steps should be taken to sustain the successes.

Figure 1 presents a visual depiction of the model. In Figure 1 the three leadership components of the model are represented by the oval shadowed boxes and the nine phases of the model by the rectangular boxes. Some of the model phases are sequential and some concurrent as shown by the line arrows. The entire process for establishing online initiatives is cyclical and the model phases are repetitive and iterative as represented by the arrows along the oval.

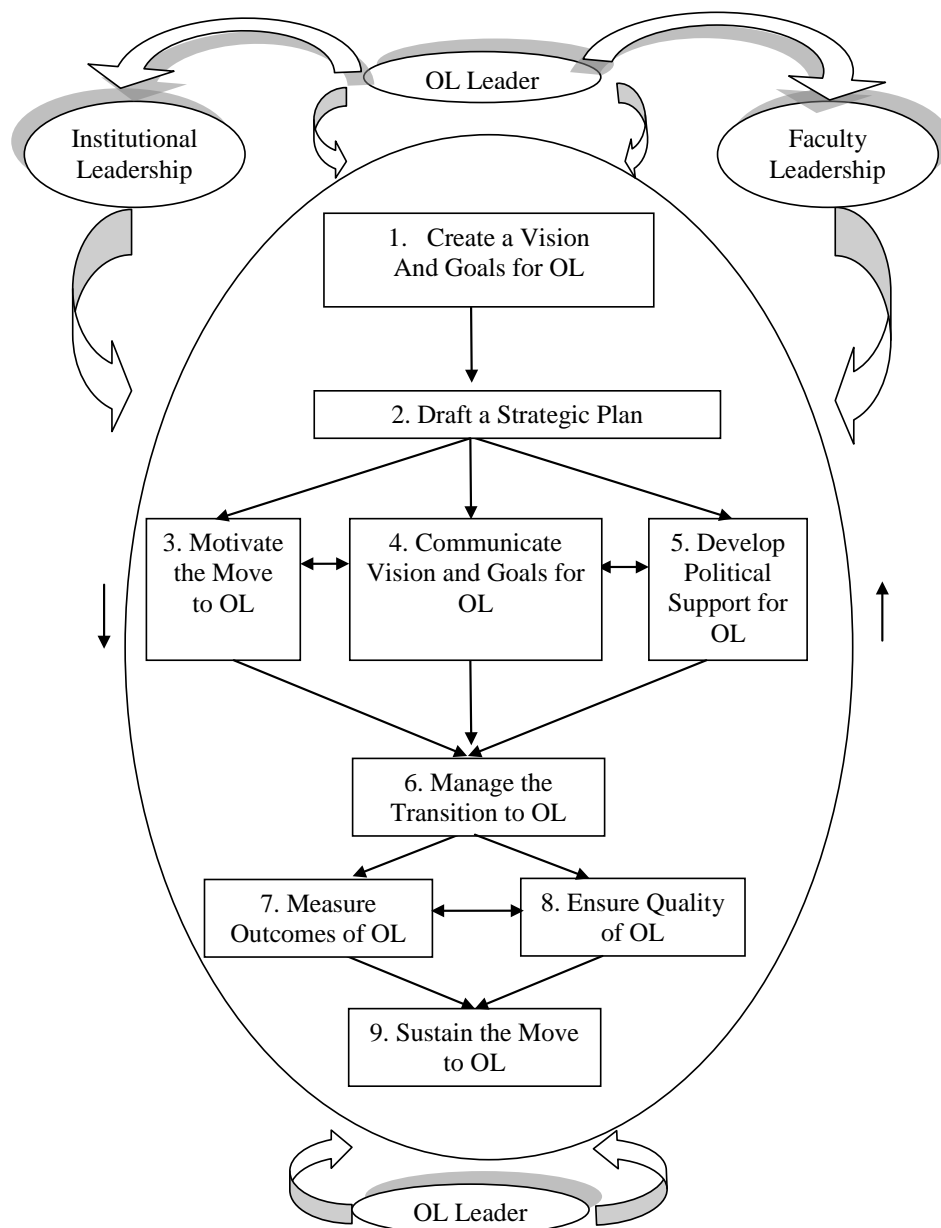


Figure 1: Leadership and change model for OL implementation. Adapted from Gopalakrishnan (2011).

Table 1 provides a summary of the nine model phases and the elements associated with them. Numerous best practices and leadership strategies emerged in this investigation and were mapped to the model phases and elements. It is beyond the scope of this chapter to describe in detail the model phases, elements, and best practices and leadership strategies. For a detailed description of all the elements comprising the model phases and the best practices and leadership strategies that are associated with the model elements, see Gopalakrishnan (2011).

*Table 1: Summary of model phases and elements*

Phases	Elements
1. Create a vision and goals for OL	
2. Draft a strategic plan	
3. Motivate the move to OL	<ul style="list-style-type: none"> <li>• Overcoming resistance to OL</li> <li>• Selling the move to OL</li> </ul>
4. Communicate vision and goals for OL	
5. Develop political support for OL	
6. Manage the transition to OL	<ul style="list-style-type: none"> <li>• Getting started with OL</li> <li>• Selecting and marketing online programs</li> <li>• Faculty development and support</li> <li>• Formulating institutional policies</li> <li>• Student support services</li> <li>• Technology infrastructure</li> <li>• Sharing resources and responsibilities</li> <li>• Funding the online initiative</li> <li>• Phasing transition to OL</li> </ul>
7. Measure outcomes of OL	<ul style="list-style-type: none"> <li>• Overall outcomes</li> <li>• Online students' learning</li> <li>• Student support services</li> <li>• Online courses and programs</li> <li>• Faculty satisfaction</li> <li>• Sharing outcomes data</li> </ul>
8. Ensure quality of OL	<ul style="list-style-type: none"> <li>• Overall quality</li> <li>• Online courses and programs</li> <li>• Student support services</li> <li>• Sharing responsibility</li> </ul>
9. Sustain the move to OL	<ul style="list-style-type: none"> <li>• Providing continuing resources for OL</li> <li>• Institutionalizing the move to OL</li> <li>• Consolidating and expanding gains in OL</li> <li>• Maintaining focus and momentum of the online initiative</li> </ul>

Two phases are further discussed to illustrate the relationships between the model phases, elements, and best practices and leadership strategies. Phase 2 involves drafting a strategic plan. Table 2 depicts some of the key issues and questions that need to be addressed during this phase. The list of issues and questions in Table 2 is not to be considered as exhaustive but as merely indicative of the types of considerations that are involved in an online initiative.

*Table 2: Key issues and questions to be addressed during strategic planning*

Issues	Key questions
1. Getting started	1. What special steps need to be taken to get the online initiative started?
2. Selecting programs	<ol style="list-style-type: none"> <li>1. What factors need to be considered in selecting programs to offer online?</li> <li>2. Which programs are going to be put online?</li> <li>3. Who is going to decide which programs are to be offered online?</li> </ol>

*Table 2: Key issues and questions to be addressed during strategic planning (continued)*

Issues	Key questions
3. Marketing programs	<ol style="list-style-type: none"> <li>1. How will the needs of existing and potential students be identified?</li> <li>2. How will online offerings be marketed to new and existing students?</li> <li>3. Who will do the market research and marketing?</li> </ol>
4. Faculty selection	<ol style="list-style-type: none"> <li>1. How many faculties will be needed to teach the online courses?</li> <li>2. Who will select the faculty to teach online?</li> </ol>
5. Faculty training	<ol style="list-style-type: none"> <li>1. How will faculty training be provided?</li> <li>2. Who will provide it?</li> <li>3. What areas will training cover? (e.g., online pedagogy, technology tools)</li> </ol>
6. Faculty support	<ol style="list-style-type: none"> <li>1. What support services will be offered to faculty for teaching online?</li> <li>2. Which campus entities will be involved in supporting faculty?</li> </ol>
7. Faculty remuneration, incentives and rewards	<ol style="list-style-type: none"> <li>1. Will faculty be paid for online course design and development?</li> <li>2. Will faculty be paid for online course delivery?</li> <li>3. Will faculty be offered course-release time?</li> </ol>
8. Course design and development	<ol style="list-style-type: none"> <li>1. Who is going to design the online course?</li> <li>2. Who is going to develop the online course?</li> <li>3. What kind of processes, procedures and timelines are needed?</li> </ol>
9. Institutional policies	<ol style="list-style-type: none"> <li>1. Who is going to teach online? Full-time or part-time faculty or a mix?</li> <li>2. Is teaching online considered in-load or out-of-load?</li> <li>3. Who will own the online courses once developed?</li> </ol>
10. Student support	<ol style="list-style-type: none"> <li>1. What support services will be needed and offered to online students?</li> <li>2. Which campus entities will be involved in supporting online students?</li> </ol>
11. Technology infrastructure	<ol style="list-style-type: none"> <li>1. What kind of infrastructure is needed?</li> <li>2. What course management system should be selected?</li> <li>3. Who is going to run the technology infrastructure?</li> </ol>
12. Sharing resources and responsibilities	<ol style="list-style-type: none"> <li>1. What resources are going to be shared?</li> <li>2. What responsibilities are going to be shared?</li> <li>3. How is this sharing going to be orchestrated?</li> </ol>
13. Funding the online initiative	<ol style="list-style-type: none"> <li>1. What is the annual budget for OL?</li> <li>2. What are the sources of revenue for OL?</li> <li>3. What resources, financial and personnel, will be committed to OL?</li> <li>4. What additional revenue streams can be established?</li> <li>5. How will revenue from OL be apportioned within the institution?</li> </ol>
14. Phased approaches	<ol style="list-style-type: none"> <li>1. What sort of intermediate goals can be set?</li> <li>2. How can the implementation be phased?</li> </ol>

Table 2: Key issues and questions to be addressed during strategic planning (continued)

Issues	Key questions
15. Outcome measures	1. What outcomes will be measured? 2. Which campus entities will be involved?
16. Quality assurance	1. How will quality be ensured? 2. Which campus entities will be involved?
17. Measuring success	1. How is success defined for the online initiative? 2. How will success be measured for the online initiative?

Note. Adapted from Gopalakrishnan (2011).

Phase 3, Motivate the move to OL, consists of two elements, *Overcoming the resistance to OL*, and *Selling the move to OL*. Each of these two elements is associated with various best practices and leadership strategies (see Table 3). In Table 3 the strategies are arranged in the order of most to least mentioned by the OL leaders with their frequencies shown in parenthesis. Table 3 also serves as an example of how the model phases, their elements, and the associated best practices and leadership strategies are connected.

Table 3: Phase 3: Motivate the move to online learning

Elements	Strategies
Overcoming Resistance to OL	1. Identifying sources and reasons for resistance (n=10) 2. Allaying fears and concerns about OL (n=10)
Selling the Move to OL	1. Garnering the support of top leadership and key individuals (n=11) 2. Educating faculty, administrators and other stakeholders about OL (n=10) 3. Providing incentives to faculty to teach online (n=10) 4. Using faculty to influence faculty about teaching online (n=7) 5. Showing how the move to OL can address specific institutional problems, market demands and departmental needs (n=7) 6. Using credible sellers to sell OL (n=6) 7. Being persistent with selling OL (n=6) 8. Establishing trust and credibility with stakeholders (n=5) 9. Launching a unit dedicated to the online initiative (n=5) 10. Realizing the limitations in selling OL (n=4) 11. Showing each constituency how OL will specifically benefit them (n=3) 12. Providing market research data about need and demand for OL (n=2)

Note. Adapted from Gopalakrishnan (2011).

## 5. Discussion

In this case study, based on a review of the literature and an analysis of data gathered from institutions and individuals successful in online education, an initial version of a model for establishing online programs at academic institutions was developed. Thus this chapter describes the first cycle of a design research project, namely the preliminary research

conducted and the development of the first prototype of the intervention. In this section this initial prototype of the intervention is discussed and next steps in this EDR project are explored.

This case study exemplifies design research in many ways. Van den Akker, Gravemeijer, McKenney and Nieveen (2006) assert that EDR has several distinct characteristics such as it is interventionist, iterative, process oriented, utility oriented, theory oriented and involves practitioners. In the study described in this chapter an OL implementation model was developed in a real-world setting to address a problem faced by many universities and colleges looking to establish large-scale online programs. The investigation was based on the theoretical proposition that the institutional move to OL is tantamount to leading organizational transformation and a conceptual framework of organizational change was used. Plomp (2009) points out that “design research follows a holistic approach, and does not emphasize isolated variables” (p. 16). Characteristic of design research, this case study also underscores the holistic approach with the notion that sustained success in OL involves addressing a host of issues in the online environment and developing comprehensive rather than isolated strategies. By including the OL leaders as research participants, this study heavily involved practitioners. Plomp (2009) asserts that in addition to the two principal outputs of design research, namely the interventions themselves and the design principles, there is a third output, the professional development of the individuals participating in the design research. This investigation provided participants the opportunity to reflect on strategies that led them to be successful OL leaders and that may have led to their professional development.

In EDR once an initial prototype of the intervention is developed it is iteratively improved and refined based on field-testing (Nieveen, 2009; Plomp, 2009). The final stage in design research is assessment and during this phase the effectiveness of the intervention in addressing the educational problem is gauged (Nieveen, 2009; Plomp, 2009). Plomp (2009) states that when a researcher has not actually field-tested his intervention “the most he can conclude is whether his intervention is expected to be practical and effective for the target context” (p. 30). To evaluate the actual practicality and actual effectiveness of an intervention, it needs to be field-tested (Plomp, 2009). The practicality and effectiveness of the intervention, both expected and actual, are two of the four criteria for high-quality interventions (Nieveen, 2009). The prototypical intervention developed in this investigation is expected to be practical, i.e. “usable in the settings for which it has been designed and developed” (Nieveen, 2009, p. 94), and effective, i.e. “using the intervention is expected to result in desired outcomes” (Nieveen, 2009, p. 94). The expected practicality and effectiveness of the Leadership and Change Model for OL Implementation are discussed next.

### **Expected practicality of the intervention**

A question that could be raised about the model involves its applicability in different institutional settings. Can the model be adopted by any type of academic institution in the U.S., or elsewhere in the world? This model was developed by examining institutions that matched a specific profile. Other types of academic institutions in the U.S. such as those under private control, community colleges, those without faculty tenure systems, or for-profit virtual universities, to name just a few, might have had to take other steps for deploying their online initiatives. The literature supports the viewpoint that even though approaches for establishing online initiatives are institution-specific, there are commonalities in the issues confronting academic institutions moving into OL. This suggests that the model developed in this study can be applied to other types of institutions. However, some components of the model may not be that appropriate or as critical in certain institutional settings. For example, at teaching-focused



institutions or at institutions without faculty tenure systems, faculty may be more inclined to devote time and effort to teaching online. Consequently, Phase 3, Motivate the Move to OL, may not be as demanding at these institutions as it can be at institutions where faculty are rewarded primarily for their research contributions. EDR, according to Plomp (2009), is context-bound and does not lend itself for context-free generalizations. Although this model for OL implementation may be applied to most settings in higher education, since the model was based on a homogenous sample population, contextual factors such as the institution's control (public or private), tenure systems for faculty, and the institution's mission and focus (research or teaching) would need to be considered when adopting the model.

### **Expected effectiveness of the intervention**

This research validated some of the characteristics of successful online initiatives described in the literature, for e.g., "institutional leadership support and commitment". In addition, several OL success factors not frequently mentioned in research studies, such as the strategy of "garnering political support for OL", emerged in this investigation. On the other hand, some factors recognized by researchers as crucial to establishing successful online programs, for instance, "faculty development and support", did not emerge as strongly in this research. Even when it validates existing literature, this study is unique in that it integrates individual success characteristics into a comprehensive framework for establishing institution-wide online initiatives that is based on the notion of organizational change.

To gauge the expected effectiveness of the intervention one could ask if all the aspects of the model are even necessary for successful OL implementation. In the context of educational change Fullan (2007) proposes a list of ten elements that, he asserts, are needed to "furnish a well-balanced reform agenda" (p. 44). He describes these elements as integral parts of a "meal" rather than options on a "menu" from which one would select an item or two. Since the model represents a holistic approach to implementing online initiatives, the different aspects of the model can be viewed as forming part of a well-balanced meal rather than a menu, i.e. they are all necessary rather than optional. However, are they all equally important?

This question pertains to the relative importance of different aspects of the model. Are some model phases, elements, or best practices and leadership strategies more critical than others in achieving OL success? The OL leaders mentioned some best practices and leadership strategies more frequently. Consequently, the data support for some model elements and phases was stronger, for e.g., for Phase 3, Motivate the Move to OL. This would suggest that some model phases are probably more critical than others for OL success. However, several explanations could be offered for the varying levels of data support for different model components. For instance, one reason for the infrequent mention of certain strategies and practices could be the short duration of the interviews with the OL leaders. Clearly, there is insufficient data in this study to categorically state that one aspect of the model is more important than others for OL success.

### **Next steps in the design research**

At the conclusion of the first cycle in this design research project it is an expectation that the Leadership and Change Model for OL Implementation can be used by any higher education institution and that adopting it would lead institutions to succeed in establishing an institution-wide online initiative. The merit of the model in terms of its actual practicality, namely its usability at institutions of higher education, and actual effectiveness for achieving sustained success in implementing large-scale online programs can be assessed in the next stage of this

design research. Applying Plomp (2009)'s illustration of Mafumiko (2006)'s design research (see Figure 8, p. 30) to this investigation it is evident that the Version I of the prototype developed in this study needs to go through an evaluation-revision cycle. As a next step in improving and refining this initial prototype, the OL implementation model could be appraised by experts and tried out in the target context. Based on outcomes, the model could be revised, iteratively. The Leadership and Change Model for OL Implementation could be field-tested by applying at an academic institution looking to establish a large-scale online initiative and then gauging its success in online education.

In design research, according to Plomp (2009), "the findings cannot be generalized to a larger universe"; however, he recommends researchers "strive to generalize 'design principles' to some broader theory" (p. 21). To arrive at generalizable design principles this investigation would need to be replicated with different populations. The model was developed by examining the online efforts of a small and homogeneous sample of participants and so this study could be replicated with a larger and different pool of successful providers of online education. Future research could also ascertain the relative importance of model phases, elements, and best practices and leadership strategies and the role of contextual factors and institutional type in the institutional approaches for large-scale online initiatives. The leadership roles of other key players in an online initiative, such as department chairs, could also be examined. This study relied solely on the perspective of the OL leaders about the success of the institutional online initiative. The viewpoints of other key figures, stakeholders and constituencies about the institutional move to OL could also be examined.

### **Key source**

Gopalakrishnan, S. (2011). *Best practices, leadership strategies and a change model for implementing successful online programs at universities*. Doctoral dissertation. Retrieved from ProQuest Dissertations & Theses (PQDT). (Order No. 3478130)

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## Educational Design Research: Designing Mobile Learning Interventions for Language Learners

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# 45. Educational design research: Designing mobile learning interventions for language learners

Agnieszka Palalas & Terry Anderson

## Abstract

*This chapter presents a case of an EDR study completed at a Canadian community college and resulting in the development of an innovative educational intervention, Mobile-Enabled Language Learning Eco-System (MELLES), as well as corresponding MELLES design principles, which emerged from this interdisciplinary research experience.*

*The first section of the chapter provides an overview of the educational problem targeted by the study, the purpose and outcomes of the research, as well as the overarching research question. The description of the EDR methodology then follows including its phases, cycles and micro-cycles. The MELLES study adopted the Integrative Learning Design Framework (IDLF) (Bannan, 2009) for design-based research and the corresponding nomenclature. Accordingly, we refer to the preliminary phase of conceptualization as Informed Exploration, followed by the design/development phase called Enactment, and the assessment phase referred to as Evaluation: Local Context. The Purpose and Outcomes and the Study Results sections of this chapter summarize the key outcomes of the study which included the development of a prototype MELLES educational intervention, replicable design principles guiding the creation of such an intervention, a refined theoretical framework of Ecological Constructivism and a comment on the professional development benefits reaped by the study participants and observers. With emphasis given to the praxis of the EDR approach, the Reflections section revisits the main features of the EDR method as distilled from our study, which demonstrates that EDR both enhanced the design and implementation of the study and was able to guide measurement of its efficacy in this context.*

## 1. Introduction and overview

### Educational problem

The increasing demand for global communications skills and especially capability to communicate in English has focused both demand and research on ways and technologies to enhance the efficiency and effectiveness of interventions designed to help learners achieve high levels of English language proficiency. Study has included a variety of teaching and learning interventions (Golonka, Bowles, Frank, Richardson, & Freynik, 2012) and more specifically a focus on studies that support learning both within and outside a formal language learning classroom (Underwood, Luckin, & Winters, 2012). Together these studies suggest that there is support for the notion that technological tools and especially those that are accessible, have potential to improve English language teaching and learning.

Mobile-Assisted Language Learning (MALL) draws on the attributes of enhanced mobility, access and flexibility afforded by mobile technologies. It “offers learning that is potentially independent of location, time and space” (Palalas, 2012, p. 26) accommodating students’ preferences and schedules. At the same time, it enables language learning that can be

informed by the context in which it is occurring. MALL “affords exposure to authentic language samples and challenges in location-specific communicative situations and provides supports required for such situated learning” (Palalas, 2012, p. 26) for example in the form of glossaries related to the context-embedded tasks (Demouy & Kukulska-Hulme, 2010).

The notions of mobility of the learner, space, technology, and time as well as informal and contextual learning have been interwoven into the latest definitions of m-learning (Brown, Börner, Sharpless, Glahn, De Jong, & Specht, 2010; Kukulska-Hulme, Sharpless, Milrad, Arnedillo-Sanchez, & Giasemi, 2011; Pachler, 2009). These aspects of mobile learning combined with the mobile network connecting resources, peers, teachers and other speakers of a language can potentially transform any context into a language learning space. Moreover, the environment in which language practice takes place is full of learning supports and affordances which can be optimized with the help of mobile devices, as described in more detail in the discussion on Ecological Constructivism. Interaction and communication with interlocutors and with the context is mediated by “cultural tools such as language and technology” (Pachler, 2009, p. 5). Mobile tools also afford a sense of ownership leading, through personalization of these tools, to individualized learning and learner agency (Pachler, Bachmair, & Cook, 2010). They also facilitate cognitive processes by making information available and presented in a way that avoids learner memory overload (Pachler, 2009).

This study investigated how the affordances of mobile technology can promote language learning based on sound pedagogic principles. We also sought to investigate what particular capabilities of mobile technologies should be incorporated in designing MALL instruction. “Language is contextually contingent; therefore, the mobility of the learner across diverse authentic contexts potentially enables situated language practice” (Palalas, 2012, p. 29). The specifics of what design supports MALL and more specifically the acquisition of aural skills as well as the related design principles had to be thoroughly examined.

The problem of inadequate aural skills amongst English as a Second Language (ESL) college learners has been identified as a key barrier to the students’ academic and professional success (CIITE, 2004; Palalas, 2009). Previous research at George Brown College, conducted prior to September 2009, determined a need for ESL intervention which would provide language learning instruction and practice going beyond the standard 52-hour course and facilitating flexible learning to accommodate the adult learners’ daily schedules and commitments. It was concluded that a blend of in-class and mobile-assisted aural practice situated in a real world language context would likely be the most effective approach to facilitate listening skills acquisition (Palalas, 2009). Moreover, findings of this previous research at the college and other educational contexts (Demouy & Kukulska-Hulme, 2010; Palalas, 2011; Rosell-Aguilar, 2007) highlighted student satisfaction with the language training offered on mobile devices experience and the need for interactive activities conducted outside classroom walls. Mobile technologies are perceived by students as helpful and appropriate for language teaching and learning (Demouy & Kukulska-Hulme, 2010). However, in response to the particular needs of our ESL students, it was vital to investigate questions pertaining to the design and delivery of a Mobile-Enabled Language Learning (MELL)<sup>1</sup> solution enabling the development of aural skills by augmenting in-class learning through effective utilization of students’ own mobile devices outside the classroom. That necessitated an in-depth understanding of the interplay of technical

<sup>1</sup>MELL is being used in place of a more widely-used Mobile-Assisted Language Learning (MALL). The modified term emerged from the findings of this study, emphasizing the role of mobile technology as an enabler of the learning process.

and pedagogical aspects of such an educational intervention and the context in which it was to be utilized. No guidelines or standards were available for creating this type of context-specific mobile-technology-enabled educational solution.

### **Purpose and outcomes**

Hence, this 2009-2011 EDR study was designed to formulate replicable design principles and demonstrate their applicability through an innovative educational intervention which eventually evolved into a Mobile-Enabled Language Learning Eco-System (MELLES). These two primary outcomes also contributed to the broader purpose of optimizing the college's ESL instruction through improved effectiveness and appeal. In addition, the study increased the awareness of the problem and the potential of the MELL approach both in the local and broader educational context. Lastly, the theoretical framework underpinning the study gradually evolved into Ecological Constructivism, melding Social Constructivism, Socio-cultural Theory and Ecological Linguistics. The key MELLES study outcomes are briefly characterized in the following paragraphs.

### ***Educational intervention: MELLES prototype***

This EDR study produced a functional prototype of a Mobile-Enabled Language Learning system created to support ESL practice and future studies of comparable MELL solutions. The MELLES intervention is a web of interlinked learning tasks and supports which can be accessed through the mobile website (Figures 4 and 5). It provides a language learning ecosystem incorporating mobile, web-based and face-to-face environments. Learners are asked to complete eight communicative tasks which are embedded in real-life language situations in the streets of Toronto. Following task directions, learners are encouraged to participate in authentic communicative challenges, negotiate meaning, and create their own language artifacts. These learning tasks combine individual focused practice with group communicative activities, rehearsed speech with ad-hoc discourse, and comprehension exercises with impromptu meaning-making challenges. As a result, learners, using their mobile phones, create authentic language artifacts (audio recordings, photos, video, and text) which they exchange through the MELLES website.

It is the mobile technology that enables the interaction among the essential elements of the design, including pedagogy, content, context, actors, and digital communication channels. By offering access to information and to others, mobile devices not only mediate individual cognitive processes but also the co-construing of meaning through interaction and communication. The mobile website serves as a gateway to the MELLES network thus connecting people and the language learning resources. Learners can access the eight language tasks and related materials from anywhere at a time of their choosing to work on them either individually or in groups. The tasks are also designed to offer flexibility in what sequence and location the individual tasks or their components are completed. Such flexibility is combined with the appropriate amount of guidance and direction - learners are guided in their learning process through task prerequisites and contextualized collaborative assignments which serve as the learning process signposts. As motivational and scaffolding measures, learners are encouraged by reminders and notifications pushed to their mobile devices to complete language activities leading to the collaborative tasks.

To ensure a seamless learning process and collaboration, the MELLES site serves as a hub - an exchange and communication platform where all resources are aggregated and shared. All task-related materials, available through the hub, are selected and validated by experts to provide personalized information as well as to aid learners in managing the abundance of language resources available on the Internet. Similarly, the learner-generated artifacts and

information contributed by them are evaluated and rated by language experts. Evaluation and feedback exchange, expert scaffolding and other interactions are made possible by connection management tools (a blend of online and offline functions) which offer either on-demand or delayed communication. To this end web-based resources were integrated with customized apps residing on the user mobile device. The resulting mobile solution enabled access to the web of MELLEES components providing improved situated aural-skill-acquisition experience.

Like many EDR interventions, MELLEES was iteratively designed, developed and evaluated to produce a pedagogically-sound m-learning solution addressing the need at hand with its specific purpose and target audience. By pedagogically-sound, we meant an intervention created and evaluated following the main theoretical framework of the study and designed to promote learning of listening skills. Building on findings of the Informed Exploration phase, a number of stand-alone mobile applications and mock-ups were initially proposed. Informed by the feedback collected through recursive Enactment and Evaluation phases these gradually evolved into MELL listening tasks before a more systemic MELLEES framework eventually integrated these tasks into a complete solution. Accordingly, a prototype MELLEES system (Figures 3-5) was created as an instantiation of the design principles, which Plomp (2009) refers to as intervention theory. The system interface, namely the project website, was accessed from students' mobile devices for the tests and evaluation of both the prototype and the corresponding design guidelines. The iterative process of the design, development and evaluation of the MELL solution, as well as the evolution of thinking facilitated the creation of successive instantiations of the design theory. In turn, enhanced understanding of the essential features and functions of the educational intervention resulted in MELLEES design principles which encapsulate the findings of this EDR study.

### ***Design principles***

While the first attempts at designing MELL models drew primarily from the design principles identified by current literature and the earlier studies at George Brown College, the conceptualization and development of the successive prototypes were driven by the EDR feedback and design guidelines emerging progressively from each cycle of the study. Ultimately, through iterative refinement, these principles evolved into what the MELLEES pilots demonstrated to be pedagogically useful guidelines (elaborated in detail in Palalas, 2012). Reflecting the results of multiple feedback loops and insights of designers, programmers, teachers, and learners, the MELLEES design principles refer to both the pedagogical and technological aspects of the intervention, and the interconnections between the two dimensions. The design principles encapsulate all the essential pedagogical characteristics of an effective MELLEES intervention, including content, procedures, context, and actors (for instance, "Integrate learner-generated linguistic artefacts: audio, video, photos, images"). They also incorporate the technical dimension of the system pertaining to the functionality, tools, and technological context required (for example "Build in personalized user progress tracking capabilities").

To clarify, the design principle refers to how to design an intervention including the desired characteristics (as identified in the process of the DBR study). Accordingly, all MELLEES design principles comprise three parts: (1) an essential characteristic of the MELL system (*substantive emphasis*), as extracted from the prototypes and the process of evaluation, (2) a strategy for realizing this unique feature (*procedural emphasis*), and (3) rationale for including the characteristic (see Table 2). The ensuing intervention theory aimed to inform future design of MELL listening practice, as well as provide an improved understanding of the praxis of mobile learning. The final MELLEES design principles are thus formulated as heuristic statements and,

as recommend by van den Akker (1999), they include substantive and procedural knowledge. All in all, the resultant design principles were formulated to guide ESL practitioners and they are not “intended as recipes for success, but to help others select and apply the most appropriate substantive and procedural knowledge for specific design and development tasks in their own settings” (McKenney, Nieveen, & Van den Akker, 2006, p.119).

### ***Theoretical framework***

To ensure pedagogically-sound outcomes, the study was guided by current second language learning pedagogy and a constructivist theoretical framework. Socio-cultural Theory (SCT) (Lantolf, 2000), was initially selected as the framework for the study and subsequently reconceptualized to reflect an evolving understanding of the appropriate MELL intervention. The SCT paradigm derives from Vygotsky’s theory of Social Constructivism and as such, integrates the elements of mediation, goal-oriented learning, the Zone of Proximal Development (ZPD), as well as a strong emphasis on language, mediation and learning through interaction in a community. SCT also regards speaking (social interaction) and the internal cognitive process of thinking as being strongly interconnected and enabled through repeated interaction with the context and other people (Lantolf, 2000). In addition, for the learner to achieve independent performance, interactivity should be supported by scaffolding coming from facilitators or peers (Vygotsky, 1978). In the Mobile-Enabled Language Learning context that scaffolding is enabled by the mobile technology which affords access to others and to learning resources.

To incorporate the important elements of constructivist learning theory coupled with the importance of a mobile context, the affordances of mobile ICT devices, and the context-embedded language learning, we applied the idea of Ecological Constructivist Learning (Hoven, 2008; Hoven & Palalas, 2011). Ecological Constructivism as a theory incorporates the multiple dimensions of Ecological Linguistics (Halliday, 1993; Lafford, 2009; Lam & Kramersch, 2003; Van Lier, 2000) and Constructivism. It encompasses “general learning and language learning more specifically, while also engendering an ecological approach to research methodology” (Hoven & Palalas, 2011). The key characteristics of the ecological nature of our research encompassed the emerging and evolving character of findings, research being done in the authentic teaching and learning context, findings being “ecologically valid”, i.e., reflecting and relating to real-life situations and exploring interventions preparing learners for real-world application of knowledge and language skills, the study applying a holistic lens to data collection and analysis including the interplay of the various aspects and actors involved in the teaching and learning relationship.

The ecological perspective on learning adds a new dimension to the SCT emphasis on the interaction and co-creation of knowledge: the significance of the dynamic real-life context offering communicational challenges, potential supports and linguistic affordances. Thus our Ecological Constructivist framework highlighted the dynamic interconnectedness between (1) cognitive processes internal to individuals, (2) the linguistic dealings and supports from other human beings, (3) the mobile tools used to mediate the relationships and provide resources, (4) the authentic language situations that while challenging learners also provide support (linguistic affordances), and (5) the environment in which the parts of this system interact. The role of the context, in this case the English speaking real-world setting, and its affordances was the focus of this ecological metaphor. Thinking in ecological and systemic terms of connectedness, relationships, processes and context allowed to develop educational designs that addressed the need for “whole language learning, namely, practicing it as a whole system (as opposed to studying the parts of speech or only one language skill in isolation), learning it in a whole context of students’ life, as part of the whole learning community, and in the whole environment of the particular language situation students encounter” (Palalas, 2012). This more holistic

approach to the process of learning, evolved from the feedback gathered in the Informed Exploration phase.

### **Professional development**

It was observed during the study that, while contributing their expertise, practitioners were able to enrich their understanding of the novel educational technology, its application in the context of language learning and, most importantly, the interplay of pedagogy and technology in practice. This two-year long study also benefitted from the progressive informal learning of all stakeholders. While students had an opportunity to design and develop real-life educational applications, practitioners enriched their understanding of the novel educational technology, its application in the context of language learning and the actual interplay of pedagogy and technology. Over time, this also produced better-informed input and research results. In addition, understanding and awareness of the practical applications of mobile learning increased across the college impacting a number of strategic and professional development initiatives.

### **Research question**

The study was guided by the following research question:

*What are the characteristics of an effective, pedagogically-sound MELLES for students' mobile devices, through which adult ESL students in a community college enhance listening skills, while expanding their learning outside of the classroom?*

Similar to other aspects of the EDR study, the question evolved replacing the original notion of a learning object with the MELLES intervention. The question inquired about the intended intervention, and what characteristics are vital for its design to be effective and pedagogically-sound, i.e., MELLES was created and evaluated following the main theoretical framework of the study and designed to promote learning of listening skills. The intervention was designed for ESL college students studying at the college programs in the area of business, accounting, hospitality, and technology. In terms of effectiveness, it was measured by participant feedback on perceived learning as well as their satisfaction with the design of the intervention and the learning experience. Using their own mobile devices students piloted MELLES in the streets and at landmarks of Toronto, where they interacted with the tasks and interlocutors (often native speakers of English), in a dynamic language environment, which both supported their language practice and challenged them to make meaning and communicate. Given the multiphase process, supplementary research questions, informed by and congruent with the various phases, emerged in the EDR process; they were then reflected in the surveys, focus groups and interview questions. Details of how the data were collected and analyzed are provided in the next section.

## **2. EDR methodology and research design**

### **Procedure**

Guided by the IDLF model (Bannan, 2009) (Figure 1), this EDR study progressed through four cycles of the phases of Informed Exploration, Enactment and Evaluation (IE-E-E); however it is worth noting that the phases did not always progress in a linear fashion, instead a particular phase of one cycle would overlap with a different phase of the next cycle; for instance when prototype 2 was being developed (Enactment), elements of prototype 1 were still being tested and evaluated providing feedback that was analyzed in a timely fashion and incorporated into prototype 2 (see Figure 2).

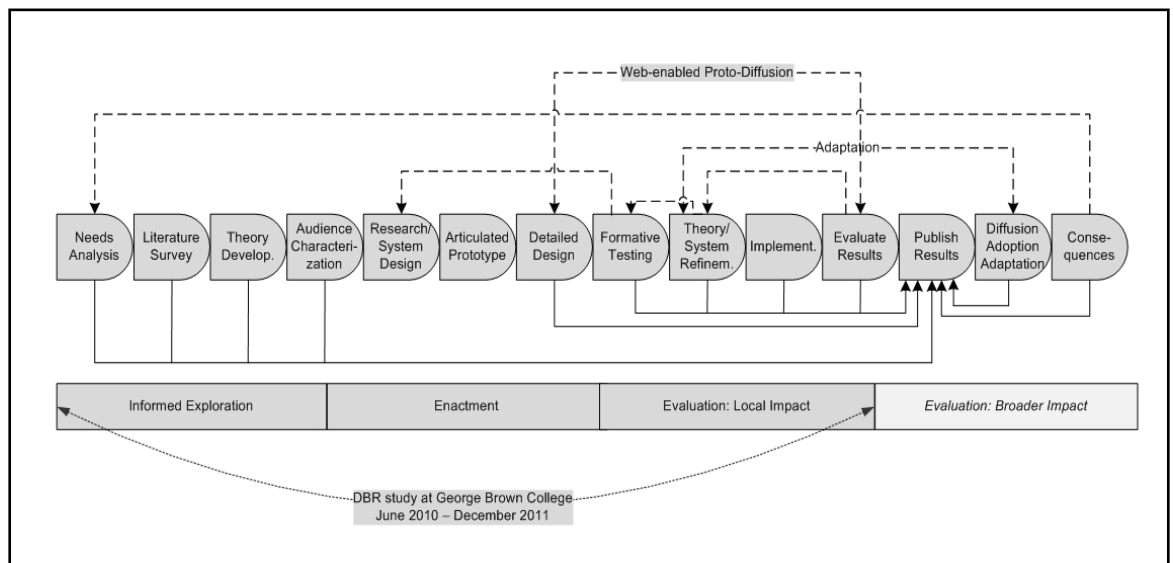


Figure 1: The ILDF model. Modified with permission (Bannan, 2009)

In the dynamic educational context it was difficult to identify all the solution requirements up-front or exclusively at the evaluation milestones, instead the design gradually emerged through cycles of the MELLES prototype evaluation and input from its end-user. Moreover, formative evaluation was conducted in an agile fashion throughout the project to manage the changing design requirements. Similarly, the various activities of the EDR process and their timelines were frequently adjusted to optimize the time and human resources available to the project. Accordingly, the three phases of the progressive IE-E-E cycles often partially overlapped (Figure 2). In total the study involved the development of three functional prototypes and implementation with 142 students (excluding the Informed Exploration focus group of 21 students and 191 students who completed the Mobile Device Usage Survey). Feedback was also collected from eight professors from the School of Design (2), School of Computer Technology (3), School of Business (1), Centre for Hospitality and Culinary Arts (1) and the Intensive English Program (1) - as well as two IT and mobile programming experts from outside the college. The data collection included 18 student and 26 expert interviews, 7 surveys and 12 focus groups. The figure below introduces the main study phases including their timelines, milestones, main activities, outcomes, as well as data and participants. The guiding questions addressed in each of the phases are presented in the table on the next page (Table 1).

Table 1: Guiding questions for each phase

Informed exploration questions	Enactment questions	Evaluation questions
<ol style="list-style-type: none"> <li>1. What is the specific ESP problem and corresponding educational needs to be targeted?</li> <li>2. What information can be gleaned from related previous studies at the college as well as existing data and research?</li> <li>3. What are the characteristics of the target population and the specific teaching and learning context (its unique requirements and limitations)?</li> <li>4. Are students and faculty ready to use mobile devices for learning? What is their m-learning experience? What are their mobile habits? What devices with what capabilities do they own?</li> <li>5. What comparable interventions have been identified in literature? What are the characteristics of their design?</li> <li>6. What preliminary design principles can be distilled from literature considering the specific context and target audience?</li> <li>7. What is the appropriate theoretical framework for the DBR study and the design of the intervention?</li> <li>8. What is the desired theoretical construct (ideal to guide the design)?</li> </ol>	<ol style="list-style-type: none"> <li>1. What are the desired characteristics of the intervention and the rationale for including them in the design?</li> <li>2. What are strategies for incorporating those characteristics into the design?</li> <li>3. What are the consequential design principles?</li> <li>4. What are the <i>sine-qua-non</i> design requirements (the specific features and functionalities, e.g., technical specifications, instructional content, site architecture, etc.)?</li> <li>5. Does the design meet the learning objectives of the intervention?</li> <li>6. What are the practical (technical, social, cultural, and organizational) influences and constraints on design and development?</li> <li>7. Are the selected theoretical construct and framework feasible?</li> <li>8. What are the processes, procedures, and roles involved in the design, development, and implementation?</li> </ol>	<ol style="list-style-type: none"> <li>1. What are the <i>essential</i> characteristics of the <i>effective pedagogically-sound</i> intervention and the rationale for including them in the design?</li> <li>2. Is the piloted design usable, valid and relevant in the specific educational context including its technology infrastructure?</li> <li>3. How is the design and the use of intervention impacted by the environmental factors, local cultures and policies, as well as the technology infrastructure?</li> <li>4. What are the specific requirements of the learning environment that impact adoption of design?"</li> <li>5. How effective is the design in terms of learning goals and target audience satisfaction?</li> <li>6. How effective are the distilled design principles?</li> <li>7. Does the design follow the selected theoretical framework?</li> <li>8. Is the intervention accessible to all end users?</li> <li>9. What's the impact of the innovative design on the studied audience and its larger environment?</li> </ol>



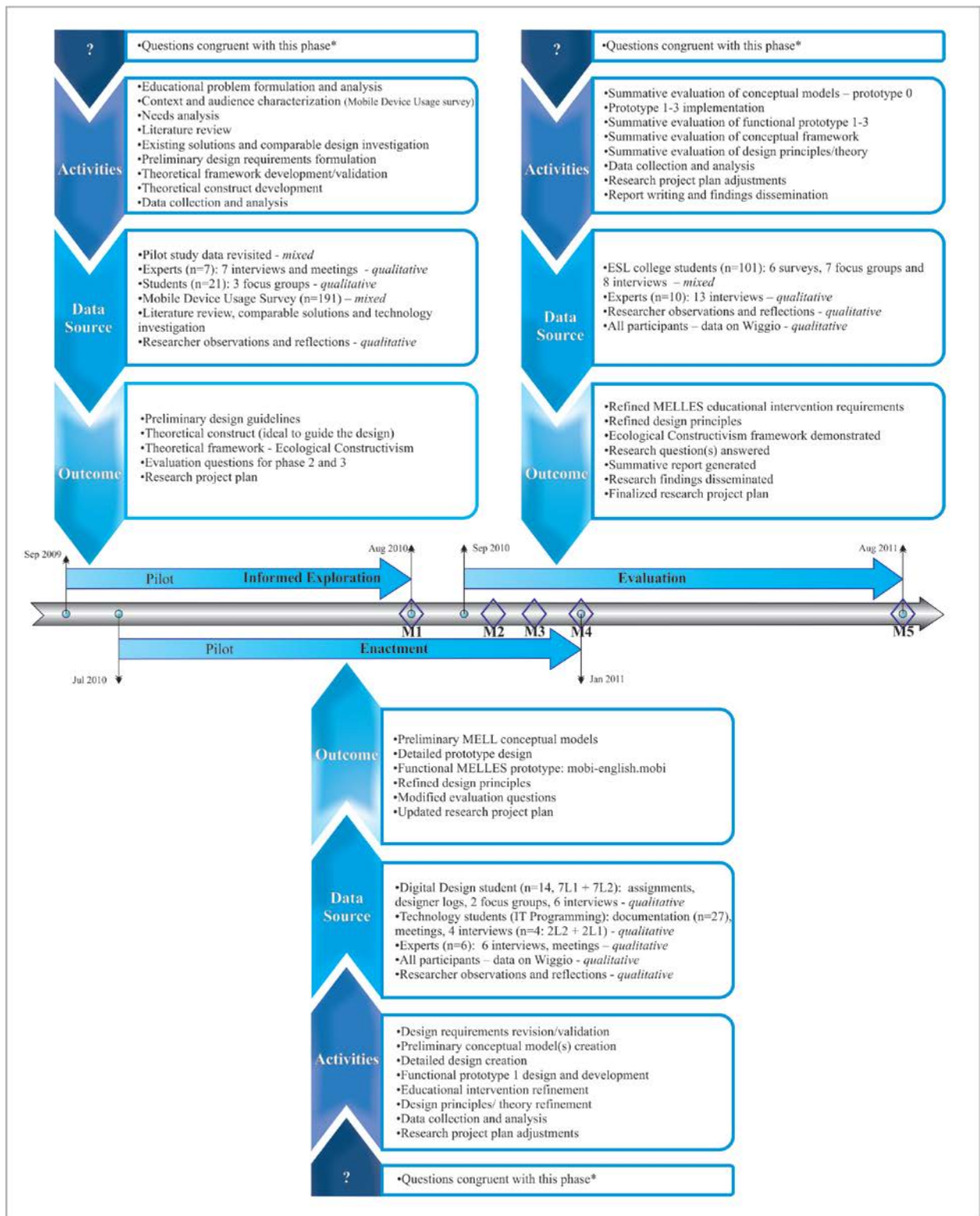


Figure 2: EDR phases: Timeline, main activities, data source and outcomes

Note. \* See the list of questions in Table 1.

The following sub-sections further describe the activities, procedures, participants, and outcomes of all four cycles of each phase. With the reader in mind, the section is organized by IDLF phases despite the recursive character of the process.

### ***Pilot study***

Before the actual EDR research, a pilot study had been carried out to test the research approach and some of its constituent elements. From September 2009 to January 2010, the pilot progressed through one iteration of the Informed Exploration and Enactment phases. Fourteen School of Design (Digital Design) students were involved in the design of the same number of MELL conceptual models following an overview of m-learning and second language acquisition offered by the researcher. Students engaged in creation of a conceptual map for mobile learning objects as well as mock-ups and proposals for the design of such software. The initial conceptual framework was then mapped out based on the investigation of literature and refined through dialogue with Digital Design students and professors.

The key finding of the pilot phase was the realization that the various mobile learning objects (MLO) created by the students did not constitute a solution to the education problem under investigation since they were disconnected MLOs and did not provide opportunities for sufficient practice of listening skills – a more holistic approach was needed. Moreover, some design and technological constraints of the m-learning intervention became apparent, for instance the cross-platform issue. Finally and most importantly, the EDR approach to the study was tested and streamlined to match the requirements of the context.

The pilot thus provided an opportunity to observe the EDR process and participants in practice and to devise the research questions (Table 1) and strategies for the study. It prepared the stage for the full round of Informed Exploration, depicted in the following sub-section.

### ***Informed exploration phase***

This stage of research began with a careful formulation and analysis of the existing educational problem followed by in-depth exploration of the target audience and practitioner perceptions to further the understanding of the specific ESL student needs. The particular college ESL learner population had been previously studied by means of exploratory research, which identified using handheld devices as an appropriate approach for enhancing listening skills of the students. Nevertheless, more focused understanding of their needs in terms of learning listening with mobile devices was needed. Accordingly, results of the earlier studies and the EDR pilot were incorporated. To re-articulate learning targets, these findings were combined with the feedback from students and practitioners from the earlier m-learning research, the School of Design<sup>2</sup>, and the School of Technology<sup>3</sup> as well as Communications/ESL<sup>4</sup> professors. The data was collected via three student focus groups, practitioner interviews and meetings, and then analyzed for common themes. The additional analysis of the context highlighted the systemic social, cultural, and organizational influences as well as constraints on the intervention design.

<sup>2</sup> Two School of Design programs were involved, namely (1) Digital Design - Advanced Digital Design Program (Postgraduate, 2 semesters) and (2) Digital Design - Game Design Program (Postgraduate, 3 semesters).

<sup>3</sup> Participants represented two School of Technology programs, namely (1) Computer Programmer Analyst (6 semesters) and Wireless Networking (Postgraduate, 3 semesters).

<sup>4</sup> These included ESL courses for Business and Communications courses for Business Administration, Business Accounting as well as Hospitality and Culinary Arts.

A survey (n=191 ESL students) of GBC students' use of mobile devices was conducted college-wide to determine what mobile devices learners owned and how they used those technologies. Its aim was to understand participants' mobile device usage patterns and m-learning experience in order to gauge their readiness for MELL solutions. Through student and practitioner feedback coupled with comprehensive review of comparable solutions and relevant literature on second language acquisition, m-learning and instructional design, the MELL listening intervention was conceptualized as an ecological system (MELLES) requiring a mobile web hub which connects the main components of the whole *flexible contextualized* learning solution: learners, facilitators, other speakers of English, language and learning resources (including the mobile listening tasks), as well as the real-world environment in which learners complete the language tasks provided by MELLES. Accordingly, the abovementioned Ecological Constructivism framework was selected to guide the study. The key interconnected elements of MELLES are depicted in Figure 3.

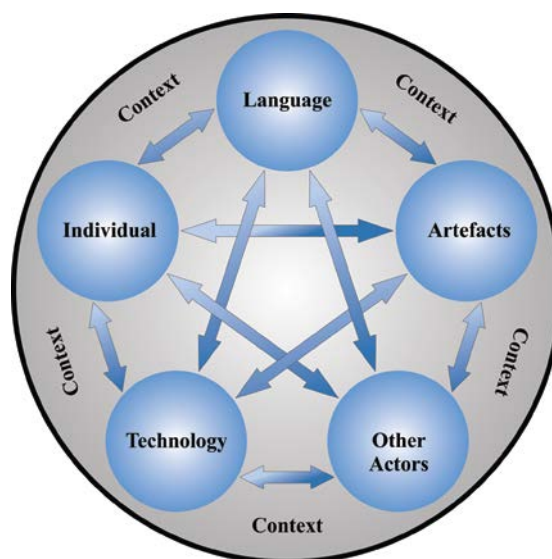


Figure 3: MELLES - Key interacting components of the system (Palalas, 2012)

The educational technology under investigation was explored via on-going dialogue with the professors and students from the Programming, Wireless Networking as well as Digital Design programs. The existing data gathered through the pilot study helped to distil the preliminary design principles and thereby provide a sound theoretical base for the progressive development of the MELLES design framework. The twenty six initial design guidelines highlighted the significance of the pedagogical aspects of the design; for instance, they emphasized the features of the MELLES intervention supporting (1) active listening and engagement in the English language speaking environment outside the classroom, (2) communication through interaction mediated by mobile devices and the device inherent functions, (3) negotiation of meaning drawing on the affordances of the context, (4) applying creative effort to communication situations, (5) mobile access to others and to multimedia linguistic resources, learning tasks instructions and materials.

A number of evaluation questions, including those concerning usability, validity, and relevance of the design, also evolved from the exploratory phase to guide the study and to form a base for the MELL surveys. On the whole, Informed Exploration resulted in an ideal which provided "a vision and a guide as well as a significant component of the measuring stick by which the ideal, as instantiated in actions within a real context, is measured" (Anderson, 2007).

### **Enactment phase**

In this highly observable production phase a number of prototypes were proposed and designed in cooperation with the School of Design and School of Technology students and practitioners. Multiple attempts at designing stand-alone learning objects and elaborate learning tasks gradually led to a more holistic solution that combined eight language tasks through a mobile website offering tools for collaborations and communications as well as scaffolding from peers and facilitators; it also served as a hub for the community of learners and an access point to linguistic resources. Hence, the ongoing evaluation of the iterative design ideas and models combined with the new ecological paradigm resulted in construction of the MELLES prototype (Figures 4 and 5). This mobile web-based system encompassed the properties and functions of the constituent MELL listening tasks, their interactions, the dynamic real-life context of the tasks, the website interface, as well as the enabling mobile technology components.

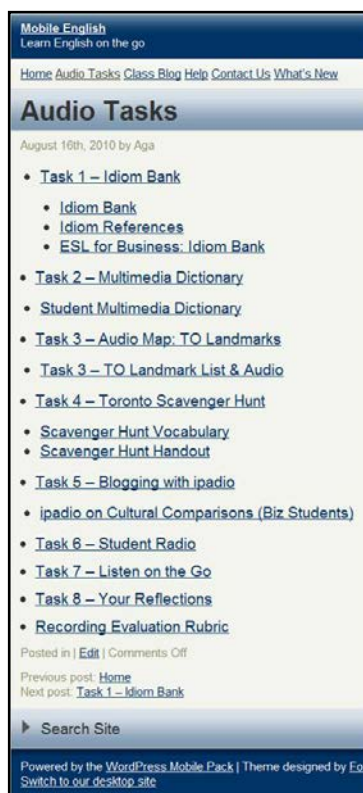


Figure 4: Screenshot of final mobi-english.mobi audio tasks (mobile interface)

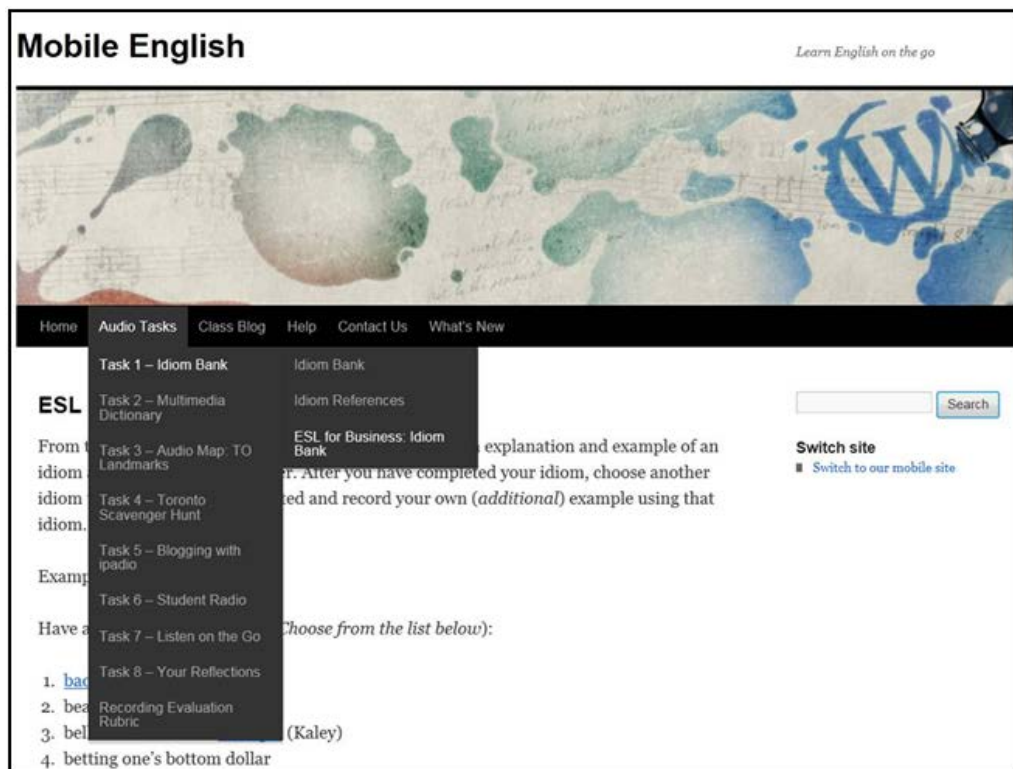


Figure 5: Screenshot of mobi-english.mobi (desktop interface)

Central to the EDR process was the design of the evolving versions of the MELL intervention which were concurrently evaluated via Phase 3 pilots and ad-hoc formative evaluation exchanged by participants at various points of the IE-E-E process. The MELLES design, development, and evaluation cycles had to be relatively systematic to correspond with the academic schedules of the programs involved. The EDR activities were coordinated with the Digital Design, Computer Programmer Analyst (also referred to as Programming), Business, and Intensive English Program (IEP) courses being integrated in the study as part of curriculum and becoming the core assignment of the respective courses. For instance, the project-based School of Design postgraduate course<sup>5</sup> had been revised to include the design of a real-life MELL prototype as its course outcome. Consequently, all students in these courses participated in the design and evaluation activities as part of their program. In fact, some also volunteered to share their feedback on their own projects. In addition, four School of Technology students and one School of Design student invested many volunteer hours outside of the program to work on the MELL design.

During Enactment, and to a lesser degree other phases of the study, the researcher was frequently invited as a Subject Matter Expert to share her knowledge of second language acquisition and m-learning with the students and practitioners. This ongoing exchange of

<sup>5</sup> Interface Design, part of Digital Design - Advanced Digital Design Program (Postgraduate). In this project-based course students, in three successive graded projects, created proposal of prototypes for MELL solutions for various mobile platforms. They discussed, created and presented in class MELL concept maps, mock-ups, MELL proposals, system requirements chart and visual presentations of the user interface design.

expertise between the researcher and the participants formed the basis for the validity and applicability of the theoretical framework necessary for the design and implementation of the m-learning intervention. Subsequently, participants produced individual MELL listening prototypes. Their designs were circulated and critiqued by their professor, the researcher and the other practitioners involved. These ideas were documented through their assignments, design specifications, designer logs, wireframes and system requirements charts. This documentation, after students' consent, was then analyzed by the researcher resulting in modifications to the proposed designs. Upon consultation with practitioners, the ensuing prototype designs served as a starting point for the development of corresponding digital constructs. Consequently, the Programming students and their professors developed the key components of the intervention prototype based on the detailed design documentation from the School of Design course. In common with the Digital Design course, the Programming course<sup>6</sup> included a mobile learning software development project as its core assignment. Formative feedback based on the student projects contributed to the final MELLES prototype design integrating eight m-learning listening tasks into a more complete solution. The mobile technology aspect of the system constituted another part of the Enactment phase. Research and trials led to the adoption of the WordPress<sup>7</sup> mobile web framework, thus optimizing cross-platform access to MELLES and its components. Concurrent with the product design and construction, subsequent versions of design principles were sketched and fed back into the system.

All research decisions, processes, constraints and other usable knowledge were recorded and analyzed as qualitative data. This feedback combined with the Evaluation: Local Context data and formative feedback shared throughout all EDR cycles and activities formed the foundation for the research outcomes. The Evaluation phase of the study is presented below.

#### ***Evaluation: Local impact phase***

This was the final phase of the EDR process - the Evaluation: Broader Impact phase suggested by the IDLF model was out of scope of the MELLES study. Interestingly, Herrington and Reeves' (2011) revision of the Baynton model has substituted development of design principles for the "broader impact" phase and thus is consistent with our study. Data essential for evaluating the product and process of the innovation design were gathered during individual prototype tests and pilots of MELLES listening tasks and the website. This feedback was collected through project meetings, interviews, surveys, focus groups, as well as captured in researcher observations and memos. Ad-hoc formative feedback was incorporated in the analysis as well. Both online (Elluminate, Skype, Wiggio, Zoomerang) and face-to-face channels were employed to capture "the intended and the unintended consequences of the intervention" (Anderson, 2005, p. 3). The resultant mixed data captured in text-based documents, images and audio files were subsequently analyzed using the NVivo analytic software, Excel, and the SPSS statistical predictive analytics software. The aggregated data were analyzed at the five

<sup>6</sup> Mobile Application Development is a last-semester course of the three-year Computer Programmer Analyst program. Through hands-on projects, students gain experience in developing and deploying wireless applications on mobile platforms.

<sup>7</sup> WordPress Mobile Pack. A toolkit which helps mobilize any WordPress site (available via Internet from any mobile platform) and its components; it includes a mobile switcher which toggles between the desktop and mobile view, a selection of mobile themes, widgets, device adaptation and a mobile administration panel to allow users to edit the site.

project milestones (noted in Figure 2). The ensuing findings were reflected in the evolving MELLEES design.

During the real-life pilots of the educational intervention, ESL students used their own devices<sup>8</sup> to complete the out-of-class listening tasks and evaluate their effectiveness. The prototype pilots were conducted with five groups of ESL students from eight different college programs representing the target group. A purposive sampling strategy was employed to recruit these student-participants. Their feedback was collected through questionnaires distributed to 6 classes of students (n= 101), seven focus groups, and five interviews (Figure 2). In addition, one Digital Design and two Programming students, as well as two external mobile and IT programming experts, tested the prototype MELLEES tasks and shared their observations through individual interviews. Practitioner input, based on their involvement in the MELLEES design work and observations of the students, offered an invaluable perspective as well. The combined participant feedback addressed questions about the intervention usability, validity, relevance in the context of the learning process, and the specific needs of the ESL student population. Hence the designers' and potential users' responses helped to identify the essential characteristics and components of the MELL system under investigation. Participants also commented on the overall effectiveness of the MELLEES approach and their perceived attainment of the learning outcomes targeted by the intervention.

The MELL system and the corresponding design guidelines were modified after each round of pilots. With data collection points being staggered across the EDR process, sufficient time was allocated for the system redesign. The considerable amount of qualitative data gathered from these EDR cycles was rigorously analyzed, coded and recoded, and thus the design characteristics identified by participants as vital for the educational intervention were systematically worked into the design.

All data sources (text, images and audio files) were integrated into the NVivo system. Codes were then generated and assigned in a cyclical fashion to phrases and sentences through repetitive thematic analysis driven by the main research question. Due to the amount of data accumulated, some pre-coding techniques were first employed and then elaborated by the Descriptive Coding (with codes identifying the topic of the respondents' comments rather than their details) in the initial stages of the analytical work and followed by Focused Coding methods (Saldaña, 2009). Focused Coding allowed for astute questioning, exploration of meaning, re-conceptualization of concepts which led to reformulating of categories. After multiple iterations and analysis of all data, the researcher was able to see the results through a more systemic lens. The analysis of relationships of the categories, their properties and dimensions as elements of the MELL system and how they interplay resulted in the final collection of codes addressing the research question. The rigorous examination of participant comments and reoccurring themes, as well as the interdependencies of those themes, led to the generation of the theory put forth by this study.

The feedback highlighted the multiplicity of required pedagogical and technological components of the MELLEES system, which was reflected in the final coding themes (NVivo nodes). The main theme categories included the following:

<sup>8</sup> Two students chose to borrow iPod Touches from the project.

**Pedagogy**

1. Pedagogic procedure – How?
2. Content – What?
3. Context – When and where?
4. Actors – Who?

**Technology**

5. Functionality – How?
6. Tech Context – When and where?

Moreover, quantitative findings validated these qualitative findings which provided a much more elaborated and informative perspective. At the same time, the effectiveness of the MELLES system built according to these requirements was measured through attitude evaluations, which indicated overall very high satisfaction with the final prototype of MELLES. The key study results are revisited in the next section to accentuate the key characteristics of the MELLES educational intervention.

**3. Study results**

While the key outcomes of the study were described in the Purpose and Outcomes section, the MELLES design principles are revisited below (see Palalas, 2012 for a detailed discussion of the MELLES educational intervention and design principles).

**Design principles**

The key characteristics of the MELLES prototype are also reflected in the design principles which evolved from its consecutive versions. Ten pedagogical and seven technology-related principles were distilled from the design and its evaluation. As mentioned before, these design guidelines have three components: (1) they refer to the essential characteristics of MELLES (substantive emphasis) and (2) the strategies required to operationalize those features (procedural emphasis); (3) the rationale for the inclusion of the substantive and procedural recommendations is also included as demonstrated in the example below (Table 2).



Table 2: Evaluation: Design principle 1

<b>Essential characteristic (Substantive emphasis)</b>	<b>Strategy (Procedural emphasis)</b>	<b>Rationale (In order to ...)</b>
Balanced combination of individual and collaborative (group work) tasks.	<ul style="list-style-type: none"> <li>• Ensure communication with others in-person and via mobile-enabled channels.</li> <li>• Build in interaction with others in person and via mobile-enabled channels.</li> <li>• Include discourse with diverse interlocutors.</li> <li>• Incorporate language problems requiring negotiation of solutions.</li> <li>• Inject fun and challenge.</li> <li>• Ensure dynamic meaning-making and negotiation.</li> <li>• Maintain regularity of group/class activities.</li> <li>• Build individual tasks to feed into the group tasks.</li> </ul>	<ul style="list-style-type: none"> <li>• Mediate communicative practice and communication (language usage).</li> <li>• Allow for cognitive and collaborative knowledge creation.</li> <li>• Enhance individual and group motivation.</li> <li>• Offer peer scaffolding and support in problematic situation.</li> <li>• Provide flexibility - time and place independent learning.</li> <li>• Accommodate different pace of learning and levels of language proficiency.</li> <li>• Support the learning network in and out of class.</li> <li>• Support cognitive processes with social process.</li> <li>• Glue the MELLES system together.</li> </ul>

Keeping the length of this chapter in mind, a brief synopsis of the design principles is presented below exclusive of the strategy and rationale discussion (see Palalas, 2012 for a detailed discussion).

The following are the ten essential pedagogic characteristics of MELLES which form the basis of the design principles:

1. Ensure balanced combination of individual and collaborative (group work) tasks.
2. Integrate learner-generated linguistic artefacts (audio, video, photos, images).
3. Incorporate game-like real-life communicative tasks.
4. Build in expert facilitation: scaffolding, feedback, and coordination.
5. Include feedback mechanism (immediate and delayed).
6. Focus on authentic listening tasks in the dynamic real-world communicative situations.
7. Design self-paced individual audio tasks to support and feed into/prepare learners for the real-life language tasks.
8. Integrate all four language skills but focus on listening outcomes.
9. Incorporate linguistic resources (task-related): relevant vocabulary, dictionaries, pronunciation, clear task directions and explanations, examples of language usage.
10. Support out-of-class learning with in-class (f2f) instruction and practice (a blend of in-class and out-of-class context).

These correspond to the following technology design principles:

1. Provide one-point access to all resources (mobile web).
2. Enable exchange of information and artifacts as well as communication through the mobile-web portal.
3. Ensure scalability, flexibility and adaptability of the system.

4. Build in a scalable rating system (from artefact to learning structures to the whole system).
5. Incorporate multimedia (including text) artefact authoring, management and usage capabilities.
6. Build in cross-platform and multi-technology support.
7. Integrate technology support and tutoring /instruction.
8. Include personalized user progress tracking capabilities.

With 47% of students strongly agreeing and 45% agreeing (7% - neutral, 1% - disagree) that MELLES provided an effective way of learning listening skills, students reported a high level of satisfaction with the system. Based on their perceived learning and positive learning experience, all participants found the intervention highly effective. However no evidence of learning was collected through formal assessments of students' progress. This limitation stemmed from the multiplicity of other variables under investigation and time constraints of the study.

In addition to the above-mentioned outcomes, the EDR method was thoroughly tested and optimized through the MELLES study which is discussed in the following section.

#### **4. Reflections on the EDR method**

In our ERD experience we co-generated new knowledge through enacting sound pedagogical theory through shared practice and reflection. The practice of producing the MELLES educational intervention based on its in-situ evaluation was made possible through collaboration and communication of stakeholders partaking in that activity - including designers, educators, students and teachers. The ensuing shared understanding of the effective practical design evolved into the MELLES design and theory. The EDR participatory design and reflective practice was augmented by the fact that many of the study participants were both system designers and its end-users contributing a unique understanding of language learner needs. Hence, the study benefited from a learning process in which designers and users learned from each other and exchanged feedback on an ongoing basis. Owing to the early feedback combined with continuous meaningful evaluation at each EDR iteration milestone and between these formal data collection points, the process adopted for the MELLES study produced outcomes which accurately reflected the changing requirements of the study participants as their understanding and thinking evolved.

It is worth noting here that the close collaboration and communication of the students, experts and the researcher throughout the study were a *sine-qua-non* for the success of this project. With most of that teamwork being systematized by the project plan and the attached course curricula, it was actually the willingness to volunteer extra time and effort that made the attainment of the study goals possible. Solid coordination of the many activities, enthusiasm of the participants, and unceasing communication were the glue of this EDR process. Moreover, meaningful communication and collaboration was achieved by engaging and empowering students participating in the study.

All things considered, it is the educational intervention meeting participant needs that is the primary measure of the progress and success of an EDR study. Accordingly, the EDR methodology worked well for the MELLES study as it combined elements of successful participative research, software development and second language learning processes. The framework shaped and evolved overtime to match our project goals and objectives, yet the following definition of EDR, proposed by Wang and Hannafin, remained the core of our research methodology:

A systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers

and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories (Wang & Hannafin, 1999).

At the same time a need for currency of the contextually-sensitive feedback, agility of response and the resulting evolution of the MELLES design were enabled by the “interventionist” nature of the EDR approach. The study was grounded in a naturalistic setting and addressed issues of everyday practice, thus leading to the development of practical solutions and reusable design principles. Considering the complexity of the educational problem and its environment, developing and evaluating the intervention in-situ engendered a more holistic and realistic exploration of the problem. Likewise, the participation of learners and practitioners produced a practical and usable solution reflecting the dynamic character of contextualized language learning. To work through the complex network of notions and their connections did require a few iterations of feedback analysis and reflection, and examining things through a real-world lens. The EDR approach, thus, allowed describing educational practice holistically, notwithstanding its complexity and local idiosyncrasy (Kelly, 2006).

We developed the design principles to expand theoretical understands (our and hopefully for others) and to guide the development of similar interventions in other contexts. We believe the design principles act as a whole, but given the iterative nature of EDR studies and necessity to adopt tools and methods to the unique characteristics in other contexts, we do not believe they are prescriptive, universal, or that they need to be enacted as a full meal. Rather they can be selected and, we believe, will be useful in other contexts, like separate items on a menu. Finally, the EDR method facilitated the concurrent and interdependent research and software development processes that fed into each other in a symbiotic relationship. The tangible results of the software development process served as stepping stones for the evolution of learning theory. In turn, the evolving theoretical framework guided all design decisions. Consistent with the ecological lens applied to the study, the EDR method provided a comprehensive and flexible plan for the design process as well as accommodated an in-depth investigation of the individual elements essential for the successful educational intervention.

### Key source

Palalas, A. (2012). *Design guidelines for a Mobile-Enabled Language Learning system supporting the development of ESP listening skills*. Doctoral dissertation. Athabasca, Canada: Athabasca University. Retrieved from <http://hdl.handle.net/10791/17>.

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## Collaborative Group Work in an Online Authentic Learning Environment: An Educational Design Research Study

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SLO • Netherlands institute for curriculum development

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# 46. Collaborative group work in an online authentic learning environment: An educational design research study

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## Abstract

*The purpose of this chapter is to provide a snapshot of a doctoral dissertation that employed an Educational Design Research (EDR) approach by describing the process and outcomes of the inquiry. The study was conducted as a two-year multi-phased EDR project to optimize adult learners' collaborative group work in a graduate level online e-learning evaluation course. The design study encompassed three iterative cycles of design, implementation and testing, and redesign. Data were collected from 23 graduate students and one instructor. Findings include the challenges the online groups encountered, attributes of groups working-well together and not working-well together, and the kinds of support learners needed during the group work process. Throughout the iterations, course components were refined to optimize students' online group work experience, while simultaneously generating design principles that could be used to support online collaborative group work in this E-learning Evaluation course, as well as be applicable in other higher education online evaluation courses or courses employing collaborative group work and authentic learning tasks as primary pedagogies. Seven design principles and 30 associated design/implementation strategies were generated and refined during the three iterative cycles. The design principles to optimize group work include guidance on the following: communication, the learning community, technology, the group work process, positive interdependence, individual accountability and engagement, and individual learning. Finally, a model for online collaborative group work for adult learners that could guide future research and online teaching was established and refined.*

*Keywords: educational design research, online collaborative group work, teaching evaluation, e-learning*

## 1. Introduction

The purpose of this chapter is to report the processes and outcomes of a two-year multi-phased doctoral dissertation study using an educational design research approach (McKenney & Reeves, 2012; Plomp & Nieveen, 2009; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006) focusing on optimizing adult learners' collaborative group work in an online course. The research context was the development of a new online course, *e-learning evaluation*, offered by the college of education at a large public university in the southeastern United States.

Evaluation is an important subject in the field of educational technology; however, relatively few educational technology graduate programs offer this type of course. In particular, there is a paucity of online courses focusing on evaluation within the context of evaluating educational technologies. The instructor of this particular course had taught this three credit-hour course to master's and doctoral students for more than 15 years prior to the inception of this study. Prior to the onset of this project, the instructor had received numerous requests for an online version of the course from faculty and students around the globe unaffiliated with the host institution.

Typically, design research begins with a need or goal defined by practitioners; in this instance, the design research project was prompted by the desire of the practitioner to offer the face-to-face course online. In the evaluation course's face-to-face learning environment, the primary pedagogy has always been "authentic learning tasks" (Reeves, Herrington, & Oliver, 2002). In brief, students work in small groups (two to four students) with real clients to plan, conduct, and report on an evaluation of an interactive instructional product. In the course, group work has always been integral to the fulfillment of the learning and project objectives. Moreover, the instructor stressed the importance of ensuring that the course in this alternative format be as effective as the face-to-face version and that it be capable of employing authentic learning tasks as its primary pedagogy. To provide an equivalent quality of learning experience for students to accomplish authentic evaluation projects effectively and meaningfully, the research team (two doctoral students, and the instructor) identified two primary challenges in moving the evaluation course online: first, supporting students' group work (McConnell, 2006; Roberts, & McInerney, 2007) to complete their evaluation projects, and second, fostering self-regulated learner skills (Zimmerman & Schunk, 2001). Two doctoral students conducted their dissertation research within the context of this educational design research study, focusing on group work (Oh, 2011), and self-regulated learning (Liu, 2012). This chapter reports only the processes and outcomes of the study focusing on online group work.

The goals of this particular study were twofold. The first was to design and refine an online learning environment for a course on evaluation to optimize adult learners' collaborative group work as they work on authentic learning tasks. The second was to develop a model and design principles for supporting online collaborative group work. In other words, the goals of the research were to contribute to the creation and extension of current knowledge on online collaborative group work and to design and sustain innovative learning environments that successfully support these collaborative activities (DBRC, 2003). The primary research question was the following: How can online collaborative group work best be supported, particularly when students need to learn through collaborating on authentic learning tasks. To further investigate the primary research question, the researchers aimed not only to understand what is happening during online collaborative group work but also how such efforts should be supported in online learning environments. The research team determined that the best way to achieve these goals and answer the research questions was through conducting educational design research (Van den Akker, et al., 2006).

Compared to the theoretical constructs supporting collaborative group work in face-to-face environments, there is no corresponding body of research studies and design theories to guide and support online collaborative group work in authentic learning environments. Although designing online learning environments using collaborative group work and authentic learning tasks has recently begun to receive scholarly attention (cf. Herrington, Reeves, Oliver, 2010), the collaborative group work aspects of online authentic learning designs have not been sufficiently discussed or synthesized in the literature within a theoretical framework nor have sufficiently usable strategies for practitioners been proposed. Design research "provides a productive perspective for theory development" (Edelson, 2002, p. 119). Through design research, researchers have opportunities to enact, test, and refine theories that can serve as both a theoretical framework and a course of action, in this case to provide support for adult learners' online collaborative group work on authentic learning tasks.

The remainder of this chapter describes 1. the research design, 2. the conceptualization of the study based on the current status of online evaluation courses, the initial learning context, and

the related literature; 3) the manner in which the course was designed and implemented to optimize students' collaborative group work experience; and 4) the lessons learned during this design research project. The chapter concludes with reflections on the research project and a discussion of the implications of the study.

## 2. Research design

By its very nature, design research is necessarily conducted in naturalistic settings (Wang & Hannafin, 2005). Instead of merely testing the effectiveness of an intervention or isolated variables in an area of interest, design researchers cope with multiple variables during intensive collaboration with practitioners as they participate in iterative cycles of design, implementation, analysis, and redesign. Design researchers engage directly in educational practice and the process of its improvement (Edelson, 2002) and deal with the dynamics and realness of educational practice while designing and implementing diverse interventions (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). As a result, the findings from the design and research process enable educational researchers to reduce the "credibility gap" between research and practice (DBRC, 2003, p. 5). That said, one has to realize that educational design research is still emerging as a distinct genre of educational inquiry and it remains unclear whether it will have the levels of impact promised by some proponents (Anderson & Shattuck, 2012; McKenney & Reeves, 2013).

In this case, the design research project enabled the researchers to improve their understanding of how students work together online in collaborative groups, clarify the difficulties they experience, and identify how students' collaborative work should be supported. Derived from the primary research question noted in the Introduction section above, the following research sub-questions guided this design research study more specifically:

1. What challenges do learners encounter when they work in groups in online learning environments?
2. What are the attributes of groups working well together and what are the attributes of groups not working well together? What makes them different from each other?
3. What supports or scaffolding do learners need during the group work process?

To investigate these three research sub-questions, the stages of the Integrative Learning Design model presented by Bannan-Ritland (2003) were adapted to proceed through four stages: exploration, enactment, implementation, and dissemination (Figure 1).

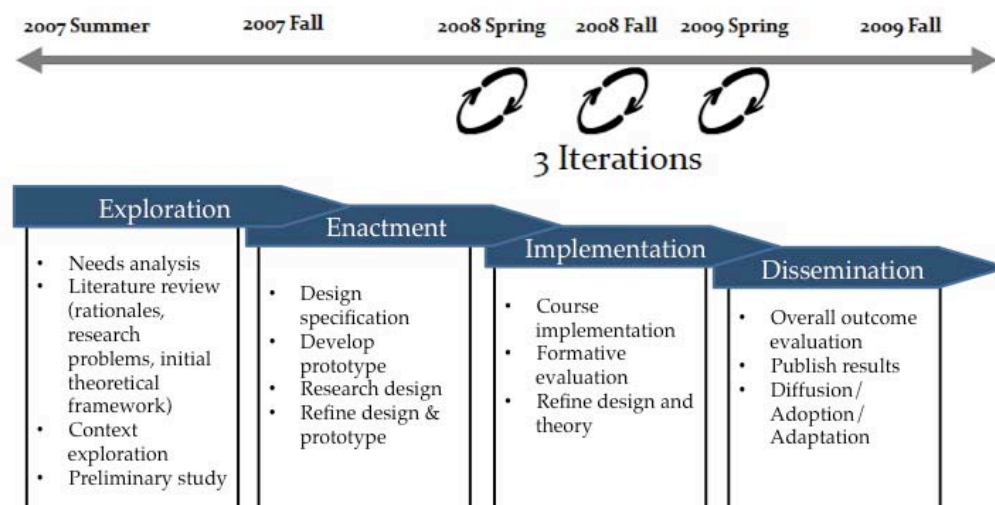


Figure 1: Four stages of design research

### 3. The exploration stage: Conceptualization of study

Much of the study's conceptualization was realized during the exploration stage when the goals of the study were clarified and a rationale for the chosen approach to designing the learning environment was established. First, to conduct the context analysis and preliminary study, the researcher served as a co-instructor in the last face-to-face evaluation course taught by the instructor. As a co-instructor, the researcher identified the general course structure, process, learning activities, materials, and related issues. Additionally, she carried out observations of the weekly class and group meetings and conducted interviews with students in the class to understand their experiences and incorporate their suggestions into the design of the new online course. Second, the entire research team conducted a needs assessment to identify the current status of online evaluation courses in higher education institutions by contacting key individuals (e.g., department heads, program coordinators, or course instructors). The design research team gathered information regarding these evaluation courses by requesting the syllabi and asking the following questions.

1. What are the primary instructional strategies and learning activities used in the course?
2. What primary assessment methods are used in the course?
3. Is the course offered online, hybrid (blended), or face-to-face? If the course is either online or hybrid (blended), what learning management systems (e.g., Blackboard, Moodle, Sakai) are used?
4. Do you think an online graduate level course about instructional product evaluation would be of interest to students in your program or college?

Through a careful analysis and synthesis, the researchers derived preliminary findings and came to three primary conclusions. First, the need for an evaluation course focusing on instructional products clearly exists because students interested in evaluation, in particular evaluation pertaining to instructional technology, desire to develop a wide array of evaluation skills and experience for their future careers. However, because of financial, instructional, logistic, and administrative limitations, this need has not been adequately met in most of the tertiary institutions contacted. Second, although evaluation courses with various concentrations were provided at multiple institutions of higher learning, few were accessible to an audience beyond the locally registered students. These results showed not only a lack of face-to-face evaluation courses offered, but hardly any evaluation courses were available online. Therefore, the provision of an online e-learning evaluation course would be beneficial as well as necessary in order to extend learning opportunities to learners worldwide having similar interests. Third, although other evaluation instructors used various teaching and learning strategies including both individual and group-based activities, use of authentic learning tasks, especially in online learning environments, was not found. Accordingly, it was clear that there was a need for design and investigation of an online e-learning evaluation course using authentic evaluation projects and supporting collaborative group work for students to complete these tasks. The full report of the needs analysis is included in Oh (2011).

While exploring the initial context and the status of evaluation courses, a literature review was conducted regarding collaborative group work, online collaborative learning, teaching evaluation, and online collaborative group work. Based on this review, the researchers came to understand the literature grounding pedagogical approaches in teaching evaluation courses, establish the initial rationale for the importance of using collaborative group work in online learning environments, and construct an initial theoretical framework that would guide both course design and research (Oh, 2011).

Design principles to specify how to support collaborative group work and enact the design of the course were also synthesized during this process. The five principles guiding the initial design were the following:

1. Establish a sense of community,
2. Enhance individual motivation and engagement,
3. Maximize the benefits of collaboration,
4. Enhance individual accountability into group projects, and
5. Provide a variety of technology that everyone can use.

In the enactment stage, these five initial conjectured principles were further discussed among the members of the researcher/practitioner team and transformed to the strategy level.

#### **4. The enactment stage: Course design**

In the enactment stage, based on the design principles and strategies derived from the literature and from student interviews from a prior study conducted in the last face-to-face course the instructor taught, the research team members had intensive discussions on how to articulate the design specifications, construct the course prototype, and design the overall research plan. Many meetings were held to refine design ideas for transforming design principles and strategies into a viable prototype course by discussing and specifying the general course structure, course schedule, learning activities, assessments, and instructional materials. The team also explored potential course management systems (CMS). Based on a consultation with a CMS expert, the research team chose Moodle, an open source CMS that would allow students at other institutions unlimited participation in the course. For project's duration after comparisons with other CMSs, Moodle was chosen for its strength in supporting student collaboration and interaction (Cole & Foster, 2007).

The original face-to-face course focused on the evaluation of instructional products in general whereas the new online version of the course focused on the evaluation of e-learning programs. To support this shift, the instructor wrote a new version of the previously used textbook so that students in the online courses from around the globe could access these new self-published chapters and related materials at no charge. The research team also selected relevant weekly readings, created pre-recorded weekly lectures, developed rubrics and assessment strategies, and specified other learning activities.

In addition to designing the overall course structure and learning environments and planning the logistics, the design research team also discussed intensively how students' collaborative group work could be supported through different course requirements, learning activities, and technology tools. Based on the five design principles previously mentioned, specific strategies related to each principle capable of supporting students' online collaborative group work more effectively were discussed and articulated during project meetings. These strategies specified learning activities, facilitation strategies for students' group work and eventual learning, and course requirements. The first design phase iteration of the course was developed based on these principles. The enrolled students spanned so many time zones that the ability to employ synchronous instruction was limited. Thus, the course was primarily delivered asynchronously using the affordances of Moodle. Figure 2 presents a screen capture of part of the Moodle website design used in this course. This particular image is from the third version of the online course.

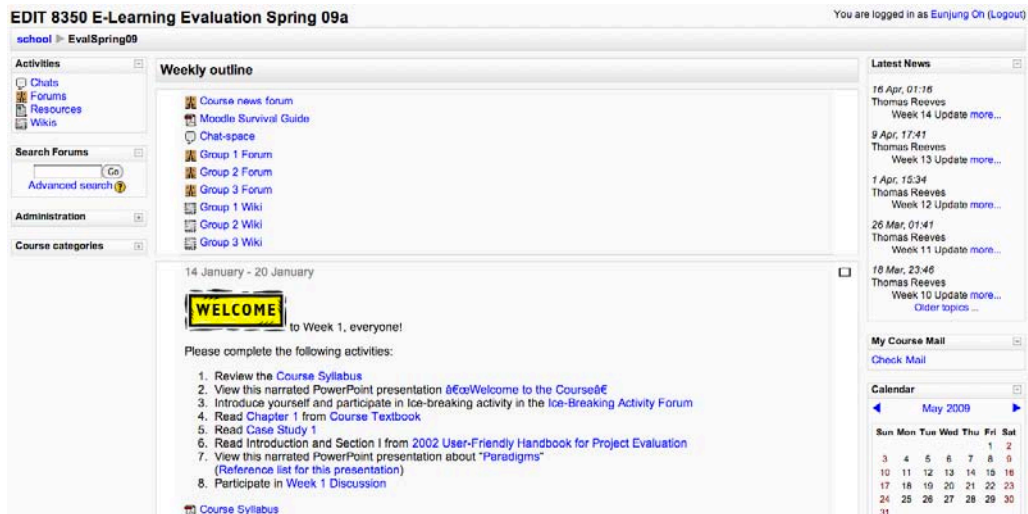


Figure 2: Course design version 3.0

### Research design

After considering the overall course structure and flow, the researcher identified the overall research process for each semester (Figure 3). To identify answers to the overall research questions, four data collection methods were selected and planned: 1. interviews, 2. surveys, 3. artifacts data, and 4. online observations (see Figure 4). More information regarding the data collection methods is provided in the Implementation Stage section.



Figure 3: Overview of research process

## 5. The implementation stage

In the implementation stage, the research team communicated and worked closely together as the course was being offered so that prompt interventions could be instituted if necessary. During the implementation stage, to improve the prototype of the course design and sharpen the underlying tentative design principles, three design research activities were performed by the design researchers: course implementation, formative evaluation, and design and theory refinement for the following iteration.

The semester-long course was implemented three times sequentially (Spring 2008, Fall 2008, and Spring 2009). The home institution of the instructor offered the course, but graduate students from other institutions could enroll and earn credit by registering for an independent study course at their home institution. During the three semesters, 34 students of 13 nationalities from 13 institutions in five countries completed the course. The first iteration had eight students, the second iteration had 16 students, and the third iteration had 10 students.

During each of the three of the course iterations, a formative evaluation was conducted to test and refine the course design, the initial development of design principles, and the model. Generally speaking, the goals collaborative groups should achieve when working on authentic tasks are a successful task outcome and substantial learning. Thus, the major areas of investigation for design and implementation refinement during each iteration were twofold: 1. the quality of students' learning outcomes as evidenced by their evaluation plans, final reports, and individual quizzes; and 2. the quality of student group work and their level of satisfaction with their group work. By examining these areas, the research team aimed to achieve the criteria for high quality interventions (Nieveen, 2009): relevance, consistency, actual practicality, and actual effectiveness.

As illustrated in Figure 3, considering the learning activities chronologically, the researchers divided individual iterations in the research process into three phases: pre-group work, during-group work, and post-group work. The pre-group work phase occurred before the groups were formed. In this phase, most of the investigation focused on students' academic and professional backgrounds, prerequisite knowledge regarding evaluation, and previous group work experience. A student evaluation skill inventory and a student profile survey were used for both course implementation and research purposes. The researcher invited students to participate in the research study, and to get to know these students better, conducted the first interviews via telephone or Skype, depending upon their preferences.

The technical definition of the during-group work phase began when the groups were formed and continued to the point at which they had completed the evaluation project. During this phase, students developed an evaluation plan in consultation with real world clients, conducted the evaluation, and reported the results. Along with the ongoing monitoring of students' group work process during this phase, the team and process assessments were conducted. To identify student progress and support their group work-more specifically, the characteristics and work styles of the groups along with any initial challenges encountered during the first group work effort, interviews with individual students were conducted after their first group assignment (the evaluation plans) were submitted.

In the post-group work phase, student artifacts (e.g., evaluation reports), self and peer assessments, instructor feedback, and course evaluations from the course implementation were collected.

After the course was finished, to investigate students' overall group work experience and identify better strategies for supporting group work, a third round of interviews were conducted.

To discuss the observed course activities, students' participation, and group work progress and dynamics spanning the three iterations of the course, the research team including the instructor held several meetings. In addition, to explore the instructor's thoughts on and evaluation of the course and the students' learning process and outcomes, the research team conducted a formal semi-structured interview with the instructor as well after the course had ended. All the data collected were used by the research team to make decisions about the kinds of interventions to provide and whether to introduce them in the same iteration that the data were collected or in the iteration following. Findings from these data were also used to expand the overall design framework of the course and the design principles to support the course.

Although there were minor revisions of the formative evaluation methods (e.g., adding and removing interview and survey questions for the focus of each iteration), data were collected consistently during the three iterations using four primary methods (see Figure 5). By using and analyzing multiple data sources, the research team strove to achieve a thorough understanding of students' collaborative group work process when they worked on online evaluation projects. The alignment of the formative evaluation questions and methods is illustrated in Figure 4.

Research Questions	Interviews	Surveys	Artifacts	Observations
1. What challenges do learners encounter when they work in groups in online learning environments?	VVV	VV	VV	V
2. What are the attributes of groups working well together and what are the attributes of groups not working well together? What makes them different from each other?	VVV	VV	V	V
3. What supports or scaffolding do learners need during the group work process?	VVV	VV	VV	V

VVV: Major data sources  
 VV: Secondary data sources  
 V: Supplementary data sources

Figure 4: Alignment between research questions and formative evaluation methods



Data Collection Methods	Data sources	Iteration One	Iteration Two	Iteration Three
Interviews	Students: Pre-group work	VVV	VVV	VVV
	Students: During- group work	VVV	VVV	VVV
	Students: Post- group work	VVV	VVV	VVV
	Instructor: Informal conversational meetings	VVV	VVV	VVV
	Instructor: formal, after semester	VVV	VVV	VVV
Surveys	Evaluation Skills Inventory	VV	VV	VV
	Student Profile Survey	VV	VV	VV
	Assessment of Team and Process	VV	VV	
	Peer and Self evaluation Course evaluation	VV	VV	VV
Archival data	Individual Quiz Results		VV	VV
	Evaluation Plan and Feedback	VV	VV	VV
	Evaluation Report and Feedback	VV	VV	VV
	Course materials	V	V	V
Observations	Weekly discussion	V	V	V
	Group meetings			V
	E-mails	V	V	V
	Wiki Group Work Forum	V	V	V

VVV: Major data sources  
 VV: Secondary data sources  
 V: Supplementary data sources  
 Empty cell: No use of data collection methods

Figure 5: Formative evaluation methods and sources for all three iterations

The formative evaluation questions did not change during the three iterations of the online course as each course iteration was subjected to formative evaluation each time. Although the same questions were addressed during all the iterations, improvements in the course from one to the next meant that the issues revealed by these questions became more and more sharply focused.

### First iteration

The first iteration was a complete intervention (Nieveen, 2009), and for the most part, its design and implementation were prototype in nature. That is, the course was not yet completely available to the public, so the recruitment of students was deliberately limited in consideration of its prototype status. Based on the design principles and associated strategies synthesized from the literature, the research team developed learning activities, resources, and general structure for the course, and set up tools in Moodle so that students not only learned substantially about evaluation but they also collaborated effectively and easily with each other during the project. The major design concern during this first try-out (Nieveen, 2009) of the prototype online course was whether the enacted pattern and intended execution would work.

The course was delivered primarily asynchronously to allow students to work on the various assignments at their own pace for individual tasks (e.g., course readings) and at the pace of their small group for team tasks (e.g., writing a draft evaluation plan). Each week, students had readings and a pre-recorded PowerPoint lecture to study individually. They were encouraged to participate actively in the weekly readings forum through their reflections on and questions about the readings. Within their designated small group, students were asked to work together to communicate with clients, write evaluation plans, develop evaluation instruments for collecting data, analyze the collected data, and write evaluation reports for their clients.

Assessment of student work was based on their evaluation plans, final evaluation reports, and participation (both individual and group work). For students to learn and work together in groups, both synchronous (e.g., online chat spaces) and asynchronous (e.g., online discussion forum) tools were provided. The instructor assumed the roles of expert evaluator, facilitator, and mentor, while helping students initiate a relationship with their clients. He communicated with them through email, the course news forum, and the weekly reading forums.

Five of the eight students in the first iteration agreed to participate in the study. An invitation to take part in the study was sent to students via email. Following the guidelines for research ethics, students had to voluntarily join the study and there were no penalties for those who opted out of the study. The five research participants were from three institutions in three countries, but in nationalities, they represented four different countries. Two students were international students in the country in which their institution was located. Regarding their academic backgrounds, two were master's students and two were doctoral students. And one student was not enrolled in a program but held a graduate degree and was a staff member at a university offering online degree programs.

The findings from the formative evaluation during iteration 1 indicated to the research team that there was ineffective and inactive communication occurred within each group. For example, delayed communication and a lack of response on the part of some group members caused frustration among others in the group and delayed the overall group process. In collaborative learning environments in which students need to establish a common understanding, students can experience difficulty in communication on four levels:

*"...contact (indicating they are willing and able to continue the interaction), perception (indicating they are willing and able to perceive the message), understanding (indicating they are willing and able to understand the message), and attitudinal reaction (indicating they are willing and able to react and respond, accept or reject the message)" (Allwood et al. 1992; Baker et al. 1999). (Paulus, 2009, p. 229).*

In online environments in which students do not know or see their group members and their instructor, it may be unrealistic to anticipate that these adult learners would naturally know how to communicate with each other actively and work together effectively and efficiently to learn the essence of evaluation and complete authentic evaluation projects.

One of the approaches that the instructor used to guide students' evaluation project was formative feedback on their deliverables. In the end, both the instructor and the real world clients expressed satisfaction with the final project outcomes; the students also said they were satisfied with their level of productivity. However, some evidence of ineffectiveness and malfunctioning was apparent in all the groups. These attributes were observable based on data from the interviews and surveys. The following are the ineffective, even dysfunctional attributes that the groups exhibited:

- a. Lack of interaction and unclear communication.
- b. Inappropriate use of tools.
- c. Poor management.
- d. Free-riders, i.e., members who contributed little to their group work.
- e. Lack of understanding of others and their contributions.
- f. Low quality of deliverables.

To overcome the challenges students encountered and help them become more functional, collaborative groups that could experience more substantial learning through group work and projects, the following supports or scaffoldings appeared to be needed to improve future iterations of the course:

- a. Modeling of appropriate communication styles and methods.
- b. Encouraging student autonomy, yet providing sufficient course structure and specific guidelines.
- c. Enhancing the sense of community and belongingness.
- d. Providing new, enhanced tools and guidelines for technology use for group work.
- e. Facilitating students' learning about evaluation.
- f. Assigning groups with careful consideration of particular students' heterogeneous characteristics.
- g. Sharing the instructor's expectations for performance.

Based on the findings, the initial five design principles and the initial model were revisited and refined. The refined design principles were the following:

1. Facilitate communication.
2. Establish a strong sense of community and help students develop a sense of belongingness to their groups and the class.
3. Provide a variety of technology tools everyone can use.
4. Maximize the opportunities for collaboration and scaffold the group work process,
5. Establish individual motivation, accountability, and engagement for active participation in group work.
6. Facilitate each student's learning about evaluation.

The design and implementation strategies associated with each design principle were refined as well. In total, 24 strategies were used for the second iteration (Oh, 2011).

### **Second iteration**

The overall focus of the second iteration as the second try-out was how to simultaneously improve communication among group members and individual learning about evaluation. First, the research team focused on strengthening the course in terms of its structure, activities, guidance, and resources so that students could be provided with an improved online environment in which to learn about evaluation. Second, the team paid particular attention to improving communication among students, instructor, and facilitators, and among students in the class as a whole and within each group because communication was the major issue and primary cause for many other challenges during the first iteration.

Eleven of the 16 students accepted our invitation to participate in the study and agreed to take part in the second iteration study. They were from four institutions in four regions in North America. Six were from the host institution offering the course and five were from other North American institutions. By nationality, they represented four different countries. Three of the 11 students used English as their second language. There were two master's and nine doctoral students.

The course overall and the students' group work process during the second iteration were improved when compared to those of the first iteration. The final evaluation project outcomes, individual quiz results, and discussion postings showed that many students in this iteration learned a great deal about evaluation.

In addition, many students mentioned that they particularly appreciated the knowledge they had acquired through the authentic evaluation project on which they had worked with peers for real clients in the final course evaluation.

Accordingly, the difficulties in this iteration were much less serious and intense. During interviews and through online surveys, students identified the following challenges:

1. Communication.
2. Differences in expectations regarding commitment and product quality.
3. Unexpected and uncontrollable events that retarded the work process.
4. Insufficient knowledge about team members and opportunities to establish a sense of belongingness.
5. Ineffective leadership in some groups

Amongst the challenges they experienced, their major concerns were problems associated with differences in expectations regarding commitment and product quality. Because of the discrepancies in expectations among the members of the various groups, and accordingly, variance in individual commitment to the real world tasks, there were communication delays, free-rider issues, social loafing and imbalanced workloads, and conflicts that resulted in group separation, de-motivation and negative group dynamics.

Generally speaking, the interdependence among group members needs to be significantly strengthened to deal with these issues. The theory of social interdependence provides useful insights and ideas for improving students' perspectives on and commitment to their group work. The theory is based on the assumptions that

- a. *the essence of a group is the interdependence among members (created by common goals) that results in the group being a "dynamic whole," so that a change in the state of any member or subgroups changes the state of any other member or subgroup, and that*
- b. *an intrinsic state of tension within group members motivates movement toward the accomplishment of the desired common goals. (Johnson & Johnson, 2006, p. 93)*

According to this theory, social interdependence influences people's actions, psychological processes, interaction patterns, and outcomes in groups (Johnson & Johnson, 2009).

Among the five groups in size from two to four members, three groups worked fairly well together in their functionality and effectiveness although they expressed and experienced some challenges with internal and external factors. However, two groups did not work well together most of the time. The ineffective and dysfunctional groups exhibited similar attributes with the groups from the first iteration. For instance, these groups had issues such as 1. low quality deliverables, 2. communication and interaction issues of frequency and content, 3. free-riders, and 4. ineffective leadership and management. To some degree, negative attributes existed in the more functional groups as well. For instance, except for one group, each group had at least one free-rider who communicated in a delayed manner, was passively engaged and contributed less to the project.

To overcome the challenges students encountered during this iteration and help future students form more effective, functional, and collaborative groups, the following supports or scaffoldings were identified for the third iteration of the course: 1. provide opportunities for discussion of their expectations, 2. guide communication and organization/management strategies directly, 3. provide guidance on effective leadership, 4. assign groups with careful consideration, 5. reach

out to students, 6. establish an atmosphere for more social/personal interactions, and 7. provide task-centered scaffolding.

Based on these findings, four of the existing six design principles were refined by adding or revising their associated strategies, and a new design principle was added to the list: provide opportunities for establishing positive interdependence. The second iteration resulted the list of 28 associated design and implementation strategies and they were used the design and implementation of the third iteration course (Oh, 2011).

### **Third iteration**

The specific focus of this iteration was decreasing social loafing issues by helping students 1. develop positive interdependence as well as 2. create a strong sense of individual accountability on the project. In total, 10 students were enrolled in this third iteration of the online course and nine of them agreed to participate in the study. Seven students were from other institutions and three were from the home institution. The student population in the third iteration was much more diverse in terms of their institutions and nationalities - six different countries in seven different institutions in the United States, Europe, and Australia. Additionally, seven of the 10 students spoke English as their second language although most of them were sufficiently fluent when working with each other. There were seven doctoral and three master's students, four male and six female. The formative evaluation involved four primary methods being consistent with the first and second iterations. However, the semi-structured interview protocols for pre, during, and post group work were slightly modified from the second iteration because of the focus shift from the second iteration to the third iteration. Differences in expectations regarding commitment and product quality were the most critical challenge that was observed in this third iteration. Improvements in course design and implementation strategies were made to decrease social loafing. For instance, the research team participated in some group meetings earlier in the semester to provide students opportunities for establishing positive interdependence. The research team helped students to have conversations regarding their expectations and goals, asked students to discuss ground rules within the team, and emphasized the importance of positive interdependence and collaboration for their successful learning. Observations of those meetings were used as supplementary sources.

During the third iteration, the students' group work in general was much improved. Compared to the first and the second iterations, there were no intense challenges such as communication, social loafing, or group dynamics that had previously caused frustration within groups. However, from the surveys and interviews, participants from all three groups reported they experienced two related major challenges: delays in the work process and time management.

In the first iteration, both groups were neither functional nor ideal. The second iteration was a combination of groups working well together and others not working well together. In the third iteration, although there were differences in work styles and group dynamics, all three groups worked well together and demonstrated many positive indicators in their group work including personal satisfaction, high quality deliverables, balance of workload, and leadership/project management. Regarding further support for the challenges students encountered, providing more task-centered scaffolding to improve time management was important.

By incorporating all the refined design principles and strategies from the second iterations, this third iteration overall was successful and students had positive experiences with their group work and the entire course. Students appreciated the refined design and implementation changes based on findings from the previous iterations.

Interviews revealed that the newly added strategies to support students' positive interdependence and individual accountability were also well received by students. Although they encountered challenges, it is worth noting that these difficulties pertained only to certain aspects of the tasks and not to working with people. Actually, it appeared that the individuals with whom they worked were helpful to them in addressing their challenges with the tasks. The findings and student outcomes corroborate that students had effective collaborative group work experiences. Although a majority of the design principles and strategies were retained, one design principle needed further refinement: maximizing opportunities for collaboration and scaffolding the group work process.

Based on the findings of the third iteration, the design principles and associated strategies were revisited and refined. The final version included seven design principles and 30 associated strategies that has been developed and refined over three iterations (Oh, 2011).

## 6. Yield of the project

According to McKenney, Nieveen, & Van den Akker (2006), who conducted a design research project in the curriculum domain, design research produces three major outputs: design principles that generate knowledge for the field, curricular products or programs that contribute to the educational practice in local as well as global settings, and the professional development of participants. Similarly, the two years of collaboration among the members of the project's educational design research team resulted in a number of desirable outcomes. First are the theoretical outcomes. *A model for online collaborative group work for adult learners*, seven design principles, and 30 associated design/implementation strategies can guide and contribute to the practice of and research on online collaborative group work among adult learners. Figure 6 presents the initial conjectured design principles that guided the first iteration and the final design principles refined from the third iteration. The findings derived from various data sources (during each iteration) enabled the research team to refine these design principles.

Initial Design Principles	Finalized Design Principles
1. Establish a sense of community	1. Facilitate communication
2. Provide a variety of technology that everyone can use	2. Establish a strong sense of community and help students have sense of belongingness to their groups and the class
3. Enhance individual motivation and engagement	3. Provide a variety of technology everyone can use
4. Maximize the benefits of collaboration	4. Maximize opportunities for collaboration and scaffold group work process
5. Enhance individual accountability into group projects	5. Provide opportunities for establishing positive interdependence
	6. Enhance individual accountability, motivation, and engagement for active participation in group work
	7. Facilitate individual student learning about evaluation

Figure 6: The initial and finalized design principles

Figure 7 presents one of the seven design principles, its associated strategies, and the specific design components/interventions. Oh (2011) includes the full report.

Principle	Design/implementation strategies	Enacted components/interventions
Positive interdependence	<ul style="list-style-type: none"> <li>Guide students to have conversations regarding their expectations and goals</li> </ul>	<ul style="list-style-type: none"> <li>In the Tips for successful online group work guide</li> <li>In the announcement of group and project assignment</li> <li>Joined the first group meetings</li> </ul>
	<ul style="list-style-type: none"> <li>Emphasize the importance of positive interdependence and collaboration</li> </ul>	<ul style="list-style-type: none"> <li>In the Tips for successful online group work guide</li> <li>In the announcement of group and project assignment</li> <li>Joined the first group meetings</li> </ul>
	<ul style="list-style-type: none"> <li>Guide students to establish ground rules</li> </ul>	<ul style="list-style-type: none"> <li>In the Tips for successful online group work guide</li> <li>In the announcement of group and project assignment</li> <li>Joined the first group meetings</li> <li>Asked groups to post ground rules in their Group Wikis</li> </ul>

Figure 7: Design principle five: Provide opportunities for establishing positive interdependence

Second are the practice outcomes (Oh, 2011), which include a robust online version of an e-learning evaluation course and all the interventions enacted and embedded in it to support the online collaborative group work in this course as well as in more global settings. These broader contexts include other online evaluation courses as well as online courses in other domains using semester-long authentic learning tasks and collaborative group work as their primary pedagogical approaches.

Finally, there is the professional development of the participants. They include:

- Researchers who played multiple roles during the project.
- The instructor who was the collaborating practitioner as well as a co-researcher.
- The students, in particular those who participated in the study by sharing their stories through the three interviews.

Figure 8 illustrates the three outcomes of this educational design research EDR project.

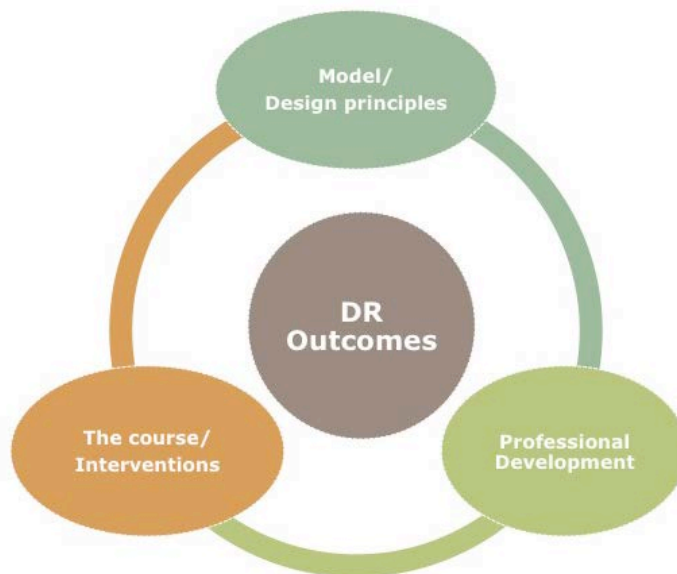


Figure 8: Three outcomes of the educational design research study

### **Reflection and implications**

This two-year multi-phased educational design research study was initiated by the aspiration of the instructor to offer his evaluation course to students in other institutions and provide them with learning opportunities. The two primary pedagogical approaches – authentic learning tasks and collaborative group work – had not always been problem free for his students during the 15 years of face-to-face classes, but the course was regarded as an exceptional learning opportunity for students who completed it. Accordingly, it was important to him that these online students have meaningful learning experiences of the same richness that his students had previously experienced. By carrying out three iterative cycles of design, implementation, data collection, data analysis, and redesign, by the third iteration the course was well delivered to students. Drawing on the extensive formative evaluation data collected from diverse sources, the findings revealed the challenges that students encountered, attributes of effective and ineffective groups, and ways to scaffold online groups when working on authentic projects. It is hoped that the seven design principles and 30 associated strategies that emerged from this study will help instructors who may be hesitant to put one of their courses online because they have thought that their courses were too application-oriented for an online environment or who may have struggled with the quality of instruction they could deliver online compared with their face-to-face classes.

An important next step of this research project would be to explore the sustainability, transferability, and generalizability of the outcomes of this design research project in both local as well as broader levels. Although the design principles, design/implementation strategies, and enacted course components and interventions were well applied in the third iteration of this course, it remains to be demonstrated that the outcomes are sustainable at the local level without the presence of design researchers. In addition, an important goal that any educational design research project should pursue is enabling the application of design research outcomes beyond local contexts (Gravemeijer & Cobb, 2006). To accomplish this objective, in the later stages of design research projects, ideally researchers should attempt to apply and test the solutions and design principles in varied settings and wider domains (Plomp & Nieveen, 2009) such as different online courses that can use online collaborative group work with authentic learning tasks. This project was conducted as a doctoral dissertation study; thus, there was a limitation in the time allocated for the study. In addition, the end of this study corresponded with the instructor's retirement. Had there been more time, the next step would have been to test for outcomes in the same course without the presence of design researchers and then to test the outcomes in a variety of settings such as other online evaluation courses or courses using comparable pedagogical approaches.

We believe that the design principles and strategies identified are robust because most were used in the second and third iterations, during which their usefulness in optimizing students' experiences was corroborated. Although a verification of sustainability needs to be conducted, we believe that the final version of the course is viable without the researchers' presence. First, the structures, activities, resources, and interventions of the course have already been developed and applied. Second, there were fewer interventions during the third iteration in which the design researchers were actually engaged. Instead, the instructor was able to implement most of the course activities and interventions independently. However, such a conclusion is mere conjecture until it is tested. The course is still offered at the university, but by a different instructor and in a blended mode. It retains many, but not all of the pedagogical design aspects (authentic learning tasks and collaborative group work) of the original course.



The application of design principles and strategies has yet to be examined in a similar environment. With respect to the analytical generalizability (Plomp & Nieveen, 2009; Yin, 2003) of the findings, these topics will be examined as ongoing future research agenda by the authors. For the most part, the findings of this study would best be applied to online courses that have an application-oriented nature with goals focused on fostering effective application and transfer of knowledge and skills to real world contexts. In terms of courses on topics other than evaluation, those involving a semester-long authentic project with clients could be candidates for application. Online instructional design courses are one type of learning context that can use the design principles and strategies derived from this study.

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## Using Digital Communication Tools and Processes to Model Effective Instruction

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SLO • Netherlands institute for curriculum development

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Credits



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# 47. Using digital communication tools and processes to model effective instruction

Monica Tracey, Kelly Unger & Kecia Waddell

## Abstract

*Most learning management systems used for delivering online instruction to instructional design students are not available for the students to use in their own professional practice. These restrictive platforms, mostly because of expensive licensing agreements, limit the opportunity for students to learn how to use learning management systems that are available in their own professional practice. This educational design research case illustrates how we designed, developed, and implemented a graduate course using Google Applications to model instructional design and delivery through digital communication tools that students could use in professional practice. This exposed learners to three main concepts and knowledge areas that could further prepare them for professional practice: (1) learn technology that is open and available to them, and their clients and students, (2) learn the content that is being covered in the course, and (3) have firsthand experience for designing instruction and teaching in an online environment by observing our design and modeling of the tools. Throughout this case we discuss the frameworks used to shape the original course design and how the course design evolved based on learners and designer/instructor findings. The findings impacted the course redesign and delivery for the next course offering over three iterative phases. The findings of this case illustrate lessons learned in designing and delivering a course using Google Applications.*

## 1. Introduction to the problem

Many universities and business corporations use learning management systems (LMS) for facilitating online instruction and communication. These systems are deemed secure for organizational content and employees. One problem that arises from a restricted LMS platform when delivering university online instruction to instructional design students is that the technology tools used in their educational environment are not available to use in professional practice. As faculty members teaching graduate instructional design (ID) students, we wanted to provide a learning environment that exposed students to ID concepts and knowledge to prepare them for practice in the field, course content, and accessible technology tools and strategies for designing and teaching in an online environment. We wanted to model instructional design and delivery through digital communication tools that students could use in professional practice. We decided to design, develop, and implement the *Introduction to Instructional Design* graduate course using Google Applications.

The intended outcome of leveraging Google Applications as the platform, for facilitating online instruction to this population, included providing a social learning experience for learners that can be applied to their real world practice. As the learners participated in the online instruction and communicated and collaborated through a variety of Google Applications, the intent was to expose them to three main concepts and knowledge areas that could further prepare them for professional practice: (1) learn technology that is open and available to them, and their clients and students, (2) learn the content that is being covered in the course, and (3) have firsthand experience for designing instruction and teaching in an online environment by observing our

design and modeling of the tools. Not only are Google Applications free and open for instructional designers to use; they are also available to their clients and students. For these reasons we decided to abandon the university provided closed online learning management system and incorporated Google Applications.

This educational design research case aimed to achieve two overarching goals. The first: How do we design an innovative open source intervention using Google Applications to model the effective use of technology integration to support individual and peer learning? The research sub-questions that guided this were:

1. What is the process of creating a higher education course utilizing Google Applications?
2. What perceptions do adult learners have regarding the functions of Google Applications?

The second goal was: What are the characteristics of a course that will allow learners to embrace the use of an open access practical learning management system while supporting learner and teacher course content knowledge acquisition? The research sub-questions that guided this were:

3. What are the perceptions of learners and teachers regarding the use/functions of the course?
4. Based on learner and instructor feedback, what course alterations are recommended?

This case study consisted of three rounds of data collection and analysis to improve and revise the *Introduction to Instructional Design* course. Each round was one semester in length and each semester included three rounds of data collection. The data was analyzed to understand learner perceptions of Google Applications and to improve and to revise the course incorporating Google Applications. This case called for an educational design research methodology, since it was a complex problem that had not been solved before, and the purpose was to document and study the design, development, and evaluation of an educational intervention (Plomp, 2009).

This chapter begins with the description of the conceptual framework for the study. The design/development section illustrates the three phases including the course the initial course design, the delivery during each phase, the findings from the data collection and the implications for the course redesign. The final section of the chapter discusses lessons learned through the implementation of this case.

## **2. Development of conceptual framework**

Literature regarding the use of Web 2.0 tools in education, and distance education provided the framework for designing, developing, and implementing the course for this case. We also utilized documentation from Google (2010) in order to understand the features and capabilities of the various Google Applications. These are discussed in the remainder of this section.

### **Web 2.0 tools in education**

Tracey and Unger (in press) report that the influx of the Internet and Web 2.0 tools in education combined with increased interest in online learning are driving universities and K-12 school districts to meet the desires and needs of their student populations. In order to adapt, faculty are now encouraged or required at a minimum to incorporate an online learning component into courses. When designing courses, faculty should choose easy to use technological tools that assist in online facilitation of strategies and activities that have been designed for increasing student interaction, collaboration, and motivation. No longer are slate and chalk and paper and pencil acceptable as the only technology tools to support collective intelligence in education.



When choosing tools, educators need an open mind to move forward with social and technological trends. Social networking tools (SNT), allow for imaginative course design (Mason & Rennie, 2008).

One way universities have selected to facilitate online learning activities is through the use of a learning management system (LMS). Most universities recommend their faculty use the licensed specific packaged LMS that they own. Most LMS' provide an online location for professors to post lectures, assignments, and course materials for students. Students can submit work and interact with the professor and other students through email and discussion boards. Along with these online learning management systems, there is another area of online learning tools that are transitioning from entertainment and for strictly social purposes toward education. These include *Read-Write Web* tools, also known as Web 2.0 tools. DiNucci (1999) was the first to use the term Web 2.0 when he was discussing the web in its infancy stage as pages of content loaded into a browser window, usually known as Web 1.0. The term Web 2.0, however, did not find popularity among the masses until Tim O'Reilly used it at the first Web 2.0 conference in October 2004 (O'Reilly, 2005). These tools are distinguishable from Web 1.0 tools, because they allow users to interact with the web without having any computer programming knowledge or experience. Average or novice users can participate by creating and sharing their thoughts and ideas directly to the web and with others. O'Reilly (2005) states that a key lesson in Web 2.0 is users add value to the information. While allowing users to share their own content, and add their own value to the social tool is crucial for collaboration and interaction, from an educational aspect, the design of the course is a necessary component for a successful collaborative online learning experience (Mason & Rennie, 2008).

In an educational design research study incorporating the Web 2.0 Application, NING.com - a platform for creating social websites, to graduate level instructional design courses, Tracey and Unger (2011) discovered that the NING was found to be a useful tool in higher education courses. The NING, which creates instant community through the use of personal profiles, a chat feature, activity streams, and forums, proved to be a more conducive environment, over Blackboard, for the professor and the students, due to its visual appeal, ease in use, and increased ability to interact and communicate. This study incorporated the constructivist ID model, Layers of Negotiation (Cennamo, 2003), which included an iterative process of collecting feedback from the students multiple times throughout the semester. An additional benefit of using the NING was the opportunity for the professor to model the use of a Web 2.0 tool for future instructional designers and educators. The results of this study illustrate the benefits of using Web 2.0 tools to increase student motivation. The NING however is no longer a free Web 2.0 tool while Google Applications, another Web 2.0 tool, is free and open to everyone.

### **Teaching at a distance**

Although the technology tool is critical, the instructor cannot simply insert the face-to-face content into a Web 2.0 tool and assume the course will be successful. Cyrs (1997) through synthesis of a variety of studies concluded that distance instructors must be competent in different skills than those teaching face-to-face. Six of the 10 include competence in skills that are also imperative for the design and delivery of face-to-face courses, including: course planning and organization, verbal and nonverbal presentation skills, collaborative teamwork, questioning strategies, subject matter expertise, and basic learning theories. The remaining 4 competencies identified by Crys (1997) were a key component to this design research study, because the course was being delivered through the online environment. These competencies included: involving students and coordinating their activities at field sites, knowledge of the distance learning field, design of study guides correlated with the technology, and graphic design and visual thinking.

Additionally, Easton (2003) noted that a successful online instructor must also consider “new paradigms for thinking about time and space for teaching” (p. 101). Learning at a distance through formal classes and informal communication is not only growing, but the tools available are also changing, becoming accessible communication tools for instructors and learners. It is imperative for educators, in higher education to integrate the use of these tools into their instruction. In order for instructional designers to be ready to utilize Web 2.0 tools for instructional purposes, instructional design faculty need to model the appropriate use of these tools, and provide effective and efficient training on integrating the tools into curricular activities. Instructional designers need highly developed skills to effectively use these tools for communication and collaboration (Unger & Tracey, 2012).

### **The use of Google Applications**

Google Applications are free and customizable tools that provide a web-based platform for teachers and students to communicate and collaborate to learn more effectively and provide students with the necessary skills for learning in the 21<sup>st</sup> century (Google, 2010). Google Applications were selected for this study because they are free to the general public and accessible by simply obtaining a Google Email address. Exposing graduate students to Google Applications also provides them with knowledge of tools that are also used in the field. The Google Applications used throughout this study included: Google Sites, Calendar, Documents, and Groups (Unger, 2012).

Google Sites is a platform where users can create a web page for posting information. In this study, students were instructed use the Google Site created by the instructor who posted all coursework materials, videos, weekly course goals and outcomes, power point slides, and additional reading assignments. The Google Site served as the hub for all course information. Google Calendar is a free calendar integrated into Gmail. Gmail is Google's free Internet-based email service. Students were instructed on how to use and share the Google Calendar for posting assignments, exams, homework dates, and other relevant dates for the class.

Google Documents is an online location for creating and sharing documents, spreadsheets, presentations, drawings, and forms. Users can create, access, and edit the documents from any computer or smart phone with Internet access. It is an online collaboration tool so users can edit documents simultaneously to save time. In this study students were instructed on how to use Google Documents in the class for collaboration with fellow students, the instructor and for assignments.

Google Groups is an online user-created discussion board. The user can invite people to join the group or have it opened publicly for anyone to join. Google Groups are formed for people with a common interest to stay connected and share information. Members of the group can add pages and start and reply to discussions, with other members of the group. In this study teachers were instructed using Google Groups when working with peers (Unger, 2012).

### **Educational design research**

Barab and Squire (2004, p.2) define design research as “a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings”. The intent of design-based research is to connect theory to practice in a direct way to improve educational innovations (Rowland, 2007). Rowland states that “design-based research involves designing and implementing a learning environment, typically one that is technology-based and that has a goal of deep learning, and simultaneously seeking through these acts of design and implementation to refine theory—primarily learning theory but occasionally design theory also” (p.14). It is research through design (Rowland, 2007).

As design research has become an important research methodology in educational research, so have numerous models most of which describe the steps in the design research process. This case, involving a technology-based learning environment, began with a review of the relevant literature as the base for the initial design of the course applying Google Applications. We then followed the guidelines of design-based research incorporating three iterations of design, implementation, data collection and analysis, revision and implementation. Replicating the Tracey and Unger (2011) study, described above, we incorporated the constructivist ID model, Layers of Negotiation (Cennamo, 2003), which included an iterative process of collecting feedback from the students multiple times throughout the semester. The following conceptual model illustrates the steps in our design research process.

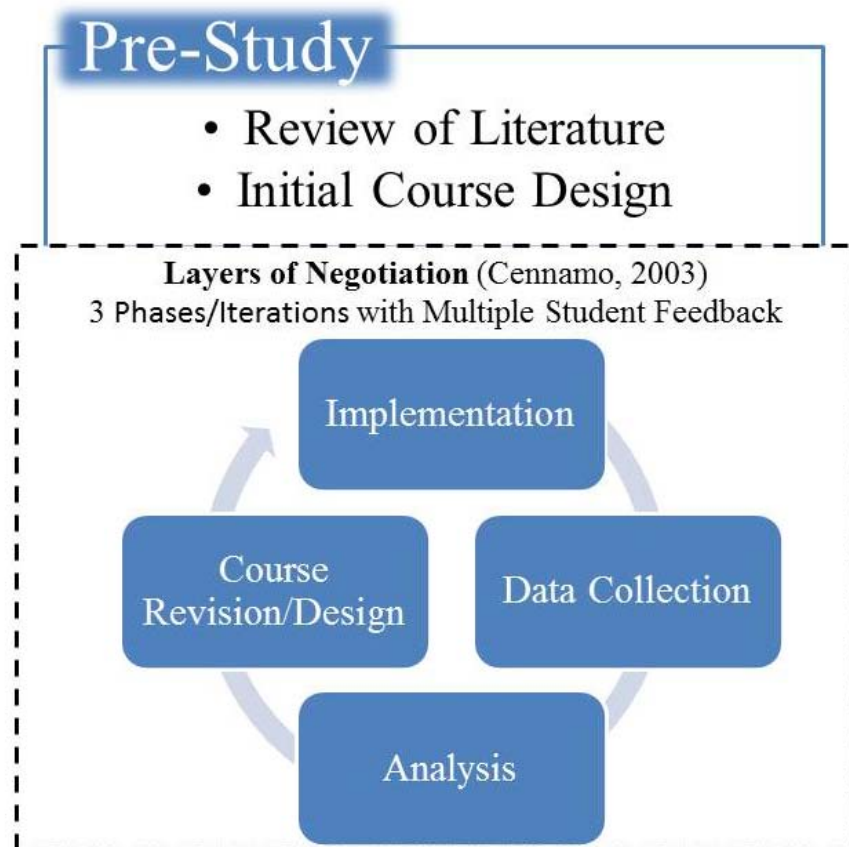


Figure 1: Conceptual model of this educational design research, this figure illustrates steps of our educational design research process

### 3. Research design

This educational design research case aimed to achieve two overarching goals. The first: How do we design an innovative open source intervention using Google Applications to model the effective use of technology integration to support individual and peer learning? The research sub-questions that guided this were:

1. What is the process of creating a higher education course utilizing Google Applications?
2. What perceptions do adult learners have regarding the functions of Google Applications?

The second goal was: What are the characteristics of a course that will allow learners to embrace the use of an open access practical learning management system while supporting

learner and teacher course content knowledge acquisition? The research sub-questions that guided this were:

3. What are the perceptions of learners and teachers regarding the use/functions of the course?
4. Based on learner and instructor feedback, what course alterations are recommended?

Table 1 illustrates the variety of data collection instruments and sources used to gather the information from a variety of sources to address the research questions.

Table 1: *Research questions, data source, and collection method*

<b>Research sub-questions</b>	<b>Data source</b>	<b>Collection method</b>
1. What is the process of creating a higher education course utilizing Google applications?	<ul style="list-style-type: none"> <li>• Literature review</li> <li>• Instructor of the course</li> <li>• Learners who participate in course</li> </ul>	<ul style="list-style-type: none"> <li>• Instructor journals</li> <li>• Learner surveys</li> </ul>
2. What perceptions do adult learners have regarding the functions of Google Applications?	<ul style="list-style-type: none"> <li>• Learners who participate in course</li> </ul>	<ul style="list-style-type: none"> <li>• Learner surveys</li> </ul>
3. What are the perceptions of learners and teachers regarding the use/functions of the course?	<ul style="list-style-type: none"> <li>• Instructor of the course</li> <li>• Learners who participate in course</li> </ul>	<ul style="list-style-type: none"> <li>• Instructor journals</li> <li>• Learner surveys</li> </ul>
4. Based on learner and instructor feedback, what course alterations are recommended?	<ul style="list-style-type: none"> <li>• Instructor of the course</li> <li>• Learners who participate in course</li> </ul>	<ul style="list-style-type: none"> <li>• Instructor journals</li> <li>• Learner surveys</li> </ul>

The primary data collection methods included three web-based learner surveys designed to collect data from the learners who participated in the course in order to address all four research sub-questions. The surveys were web-based questionnaires created using Google Forms, which allowed data to automatically populate into a web-based spreadsheet. The surveys were distributed to the learners during Weeks 5, 10, and at the conclusion of the course. Each web-based questionnaire was estimated to take approximately 15-30 minutes to complete. Participants were allotted seven days to complete each of the surveys with a reminder email being sent on the fourth day. The Week 5 web-based questionnaire was designed to gather data regarding our participants prior use of various Google Applications in other courses, for personal use and for employment purposes; and to gather participant perceptions of whether coursework engagement through use of Google Applications helped or hindered their learning up to that point. The Week 10 web-based questionnaire used an open-ended question design to discover recurrent perceptions on whether Google Applications helped or hindered their learning. The end of course questionnaire was adapted from John Keller's Course Interest Survey (CIS) of 34 statements to be answered using a five-point ordinal scale-- 1 Not True, 2 Slightly True, 3 Moderately True, 4 Mostly True, 5 Very True. The end of the course survey gathered quantitative data that measured students' reactions to classroom instruction with reference to a specific learning condition--Google Applications. The instructor reflection journal was a secondary data collection method used to reflect upon successes and failures of both the course and the research study during each of the three iterations. During the course, the instructor kept a Google Document, documenting her thoughts, reactions and ideas regarding the use of Google Applications. Journal reflections included general comments on the use of particular applications along with specific changes that needed to be made for the next iteration.

The data from this secondary source was used to enrich the findings from the survey data to address research sub-questions 1, 2, and 4. Because research sub-question three focused solely on the perceptions of the learners, the instructor reflection journal could not be used to address that sub-question. Per the research protocol, the first round of data analysis involved individual identification of themes that emerged from the questionnaires and reflective journals by two or three research assistants who were authorized to conduct data analysis. The data was analyzed using an inductive analysis approach with constant comparative coding using Microsoft Word following the procedure outlined by Ruona (2005). Round two involved a collaborative analysis of the identified emerging themes, and consensus on any items that differed. The final analysis of the data included a summary of suggestions for course revisions and improvements to be used for the redesign of the course.

### 3. Design and development phase

The purpose of this case study was to develop an innovative intervention incorporating Google Applications in a graduate instructional design course to model effective use of technology integration to support individual and peer learning. Specifically we were interested in documenting the process of creating a higher education course utilizing Google Applications, the student perceptions of the function of Google Applications and its impact on learning, and what course alterations must be made to improve the course.

Throughout this section we will discuss how the course design was presented to the learners, the findings based on the data analysis, and the implications the findings impacted the course redesign and delivery for the next semester. Table 2 illustrates the phases in the study and the activities within each phase.

*Table 2: Phases in the educational design research case study*

<b>Phase I: Winter 2011</b>	<b>Phase II: Fall 2012</b>	<b>Phase III: Winter 2012</b>
<ul style="list-style-type: none"> <li>• Course</li> <li>• Data Collection</li> <li>• Findings</li> <li>• Course Redesign</li> </ul>	<ul style="list-style-type: none"> <li>• Course Delivery</li> <li>• Data Collection</li> <li>• Findings</li> <li>• Course Redesign</li> </ul>	<ul style="list-style-type: none"> <li>• Course Delivery</li> <li>• Data Collection</li> <li>• Findings</li> <li>• Course Redesign</li> </ul>

#### **Initial course design and participants**

*Introduction to Instructional Design (IT 6110)* is a required graduate level course for all Instructional Technology master and doctoral students. The course, initially taught face-to-face and online utilizing the university LMS, Blackboard was redesigned incorporating Google Applications for the Winter 2011 semester. The initial design included a Google Site that served as the hub of the course. The Google Site had links for announcements, the syllabus, also posted as a PDF document, weekly readings, weekly lectures from the instructor that also included short YouTube videos on identified topics, assignments, and Google How to Videos created by the instructor for students to view and follow step by step instructions on how to create Google Documents, work in the Google Calendar and in Google Groups. A Google Group was created for weekly discussions with the entire class and the instructor. This discussion board was accessed through a link posted on the Google Site. In addition to the assignments, lectures and discussion board, the instructor assigned a buddy system at the end of the course for students to review each other's work prior to final submission.

### ***Phase 1: Winter 2011***

After the initial design of the course, Phase I included the first delivery of the course design to graduate students enrolled in the *Introduction to Instructional Design (IT 6110)* during the Winter of 2011. There were 10 students enrolled in the course, but completing the surveys was voluntary, so the number of participants for each survey varies.

#### *The findings*

Prior to taking the course only a few students had any previous exposure using the Google Applications Groups and Sites. The Google Application that students had the greatest exposure prior to taking the course was Documents. Of the students who used these Google Applications prior to this course most did so in other courses for the main purpose of collaborating and sharing work with others. One of the students who had previously used all of these Applications also had experience using the Applications for career and personal purposes.

#### *Week 5 survey*

Students participating in the survey during Week 5 of the course perceived that the Google Applications helped them in their learning of the course content. The majority of comments regarding how or why Google Applications assisted with their learning stemmed from their positive perceptions of the tools. Students found that the tools were easy to use, and especially beneficial for collaborating and sharing work with others. The opportunities to receive instant feedback from others were also beneficial because they were notified when someone responded. Students also benefited from learning the how to use these tools, which can also be used in their own practice.

The majority of students perceived that the Google Applications did not hinder their learning, but did make comments about various technology issues they encountered. Some of the technology issues included comparability of MS Office with Google, having to have too many windows open to view all content, cumbersome navigation and layout of the discussions on Groups, and personal technology issues not impacted by Google. The one student who found that the Google Applications hindered her learning referenced that the tools were new to her, and having to spend time learning the tools caused her anxiety in which she could not focus on the content. At this point in the course the students did not have any suggestions for improving the course, but most of them did leave positive feedback on how they were enjoying the course thus far.

#### *Week 10 survey*

Students participating in the survey during Week 10 of the course perceived that the Google Applications helped them in their learning of the course content, while a few mentioned that it neither helped nor hinder their learning. The majority of comments regarding how or why Google Applications assisted with their learning stemmed from their positive perceptions of the tools. Similar to Week 5, students found that exposure to these tools were a benefit because the tools were easy, free, and accessible to use in their own practice. Again, the students perceived the tools beneficial to their learning because of being able to collaborate, interact, and sharing work with others easily. Students also commented that they could benefit from having all of the tools, such as Ustream and Groups, in one location.

At this point in the course the students suggested that the instructor should distribute Google Applications job aids at the beginning of the class and find a better format for facilitating the online discussions. Two of the students did comment that they liked the way the instructor provided a variety of communication methods, and benefited from synchronous communication.

### *Course completion survey*

While most of the students participating in this course had very little to no exposure to Google Applications, they found the course to be a positive experience. Comparing the data that was collected throughout the semester via the two surveys, we found that the students encountered a positive learning experience with the Google Applications that were used in this course. They perceived that the use of Google Applications helped them with their learning of the course content. The students found Google Applications to be appealing because they were easy to use and increased the opportunities for student interaction and collaboration on independent work, projects, and course content discussions. While the students liked the ease of the tools for collaboration, they still found the discussions within the Google Group to be cumbersome, and recommend finding another way to facilitate the online discussions. The students also suggested providing a Google Applications job aid for them to use at the beginning of the course. Some students felt that Google Sites provided an easy way to have all of the course information stored at one central location, but others did recommend that this could be better in future course offerings.

### *Implications for course redesign*

There were key findings from the student data and the instructor journal that impacted the redesign of the course for Phase II. Students requested a centralized location for the course content, the distribution of Google Application job aids prior to the beginning of the course, and wanted a different method for online discussions. The instructor identified the need to create the syllabus in Google Documents and embed it onto the site. This allowed for syllabus changes as the semester progressed without the need to send and post revised versions. Students could review the syllabus weekly to see if any adjustments were made to the course. The instructor also noted the need to add weekly outcomes to the assignment checklist and to create a form to assess their understanding of the syllabus. The most critical redesigns however occurred in the layout of the Google Site and the use of Google Groups for discussion. Students repeatedly indicated that they had difficulty in following all of the locations they had to go to review course content, understand the assignments, view videos etc. The Google Site was reorganized with a link titled for each week. For example, Week 1 included the topic of the week, a list of outcomes students should achieve by the end of the week, the instructional materials including all videos, readings and directions for the assignments. This provided a centralized location for all of the course materials per week making it easier for the students to understand the weekly requirements. The Google Group for discussions was removed. Feedback from students indicated they appreciated the *Buddy System* for the final assignment of the course but had a difficult time collaborating with other students while working in the Google Group for discussions. We decided to assign small *Peer Groups* of 4 students for the entire semester. The peer groups worked in a Google Document answering discussion questions and working on peer assignments. The instructor had access to the document and responded to the students throughout the week, guiding their learning. Based on the instructor journal with the student feedback, we discovered a need for individualized communication with each student and the instructor. We added a weekly reflection journal with the student and the instructor in a Google Document. Each student was required to answer weekly reflection questions in a Google Document they shared only with the instructor. The instructor provided detailed feedback to the student, once again, guiding their learning.

### ***Phase II: Fall 2011***

Following the redesign of the course at the end of Phase I, Phase II included the second delivery of the course for graduate students enrolled in the *Introduction to Instructional Design* during the Fall of 2011. There were 15 students enrolled in the course, but completing the surveys was voluntary, so the number of participants for each survey varies.

#### *Course delivery*

Prior to the first week of the course, each student received a Google Application job aid to help familiarize themselves with Google Applications. The syllabus was created in a Google Document and embedded in the Google Site along with the Google Calendar. A short form was added to the end of the syllabus page where students could assess their understanding of the syllabus by answering a few short questions. This ensured all students had a clear understanding of the course outcomes allowing them the opportunity to focus on using the Google Applications. The Google Site was revised with weekly links housing all of the content students needed to achieve the weekly outcomes. The peer groups were assigned and each group created and shared a Google Document with each other and with the instructor for discussions. Finally, the addition of the individual weekly reflection journals with the student and instructor were added. The instructor also added online office hours, 17 hours per week, where students could access the instructor through Google Chat. This allowed students the opportunity to communicate with the instructor more frequently for assist with clarification of assignments and course content along with questions about the Google Applications. It also modeled the communication tools to the students.

#### *The findings*

Prior to taking the course only a few students had any previous exposure using the Google Applications Sites. Once again, the Google Application that students had minimal exposure to the most prior to taking the course was Documents. Some students also indicated they had experience with Google Chat. Of the students who used these Google Applications prior to this course most did so in other courses for the main purpose of collaborating and sharing work with others however one student taught how to use Google Sites to teachers in her school district.

#### *Week 5 survey*

Students participating in the survey during Week 5 of the course perceived that the Google Applications helped them in their learning of the course content. The majority of comments regarding how or why Google Applications assisted with their learning stemmed from their positive perceptions of the tools. The Google Application job aid videos proved extremely successful here. Students found that the tools were easy to use, and especially beneficial for collaborating and sharing work with others. Students indicated they preferred Google Sites to Blackboard and stated they liked the accessibility to Google via any computer or mobile device for efficient time management on the run. Students also commented on the ability to access the instructor frequently through Google Chat from their mobile device. They appreciated the constant weekly communication with the instructor through the individual reflection journals and believed it helped them understand the course content.

The majority of students perceived that the Google Applications did not hinder their learning, but did make comments on the use of the peer review document. Students did not like the constant editing to the document by other group members and one student indicated the document got very large very quickly with the group responses. The students did not make any suggestions for course revisions at this time.



### *Week 10 survey*

Students participating in the survey during the midpoint of the course perceived that the Google Applications helped them in their learning of the course content, while a few mentioned that it neither helped nor hindered their learning. Students indicated that the tools were intuitive and easy to use and that the content was organized in a logical manner. This confirmed our redesign of the Google Site with weekly links. Students indicated it was easy to collaborate using Google Chat features and that the Google Applications allowed them to focus on academics because of the one-stop learning environment.

The students had a few suggestions for improving the course including setting up the homepage as a single column instead of two columns so the most important information would always be at the top of the page when the students access the page. This change was made immediately. The students requested the peer documents be broken down into shorter documents for ease of navigation. This change was also implemented immediately.

### *Course completion survey*

While most of the students participating in this course had very little to no exposure to Google Applications other than the use of Google Documents, they found the course to be a positive experience. They perceived that the use of Google Applications helped them with their learning of the course content. The students found Google Applications to be appealing because they were easy to use and increased the opportunities for student interaction and collaboration on independent work, projects, and course content discussions. They particularly liked the ease of access to the Google Sites via mobile devices enabling them to work anywhere, anytime along with the increased access to the instructor and the individual communication with the instructor through the individual reflection journals in Google Documents.

The students did make a few course improvement suggestions. The addition of the Peer Groups in Phase II created the need for instruction on how to view the revision history function within Google Documents so that students could monitor revisions made on their peer document. The students also indicated the Peer Group Google Document became too large and cumbersome to work in asking the instructor to break down the peer group discussions to shorter documents. Finally, students requested the home page in the Google Site be set up as a single column instead of a two-column format with the most recent announcements placed at the top of the page for easy access when visiting the Google Site.

### *Implications for course redesign*

The redesign after Phase II was minimal in comparison to Phase I however significant feedback was used to revise the peer group discussions in the course. The peer group discussions in Google Documents were much improved over the Google Groups function used in Phase I but some adjustments were required. A Google job aid was created for instruction on how to view the revision history function within Google Documents so that students could monitor revisions made on their peer document. This job aid was added to the other job aids provided prior to the beginning of the course. A new Peer Group Google Document was also used for each discussion week, meaning a new document was created each week by the peer group and shared with the instructor. This resolved the issue of the document becoming too large and cumbersome to work with. The home page in the Google Site was adjusted to have a single column instead of a two-column format with the most recent announcements placed at the top of the page for easy access when visiting the Google Site. The students were extremely positive about the individual reflection Google Document shared with the instructor so this addition was kept for Phase III course delivery. The students also responded positively to the addition of online office hours via Google Chat, so those hours remained during Phase III.

### ***Phase III: Winter 2012***

After the final redesign of the course at the end of Phase II, Phase III included the third delivery of the course for graduate students enrolled in the *Introduction to Instructional Design* during the Winter of 2012. There were 7 students enrolled in the course, but completing the surveys was voluntary, so the number of participants for each survey varies.

#### *Course delivery*

Once again, prior to the first week of the course, each student received a Google Application job aid to help familiarize themselves with Google Applications. During this phase however, students also received instruction on how to view revision history within Google Documents to monitor revisions made in the Peer Group Google Documents. All other Applications remained the same with the exception of the Google Site Homepage that was adjusted to have a single column instead of a two-column format with the most recent announcements placed at the top of the page for easy access when visiting the Google Site.

#### *The findings*

Prior to taking the course only a one student had any previous exposure using the Google Applications Sites. Students did not have exposure to Google Documents prior to this course. Some students indicated they had experience with Google Chat while using their Google Gmail for personal use.

#### *Week 5 survey*

Students participating in the survey during Week 5 of the course perceived that the Google Applications helped them in their learning of the course content. The majority of comments regarding how or why Google Applications assisted with their learning stemmed from their positive perceptions of the tools. Students found that the tools were easy to use, and especially beneficial for collaborating and sharing work with others. Students commented on the easy navigation of the tools but were particularly receptive to the collaboration tools including working as a peer group synchronously in a Google Document, Chatting while working in a Google Document and the ability to capture those Chats. Students overall felt positive about Google Applications and their learning experience. The majority of students perceived that the Google Applications did not hinder their learning. The students made no suggestions for improvement at this time.

#### *Week 10 survey*

Students participating in the survey during the 10<sup>th</sup> week of the course perceived that the Google Applications helped them in their learning of the course content, while a few mentioned that it both helped and hindered their learning. Students indicated that the Google Applications were very helpful for peer collaboration, and that the Google Documents were helpful for document sharing. The students also commented on how Google Documents made communication (feedback) easy between peers and the instructor. Students commented on how they learned they could share Google Documents with others, how to collaborate in a document synchronously with others in their peer review groups and that the Applications were user friendly and quick to learn. The students suggested the inclusion of 1-3 webinar forum sessions to enhance the feel of the virtual classroom online experience and wanted a grade port added to Google since that was the only thing missing from this LMS for them. Grades continue to be posted on the University Blackboard system.

### Course completion survey

Once again we found that the students encountered a positive learning experience with the Google Applications that were used in this course. They perceived that the use of Google Applications helped them with their learning of the course content. Students in this group responded most positively to the communication aspects in Google Applications, the ability to collaborate with their peers and with the instructor in Google Documents and via Google Chat, the sharing of Google Documents and the ability to simultaneously view discuss and alter a document in their peer groups from remote locations.

### Implications for course redesign

Phase III ended the study and because the suggestion of webinars included in the course was outside the scope of studying the use of Google Applications, there was no other course redesigns done at this time. Table 3 illustrates the responses from two of the three web-based surveys (Week 5 & Week 13) from all three phases of the study.

Table 3: Summary of web-based survey data from three phases

<b>Demographics</b>	<b>Phase I: Winter 2012</b>		<b>Phase II: Fall 2011</b>		<b>Phase III: Winter 2012</b>	
Introduction to Instructional Design (IT 6110) graduate level students						
<b>Students Enrolled</b>	10		15		7	
<b>Awareness/Use of Google Applications prior to Course</b>						
<b>Tools</b>	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>No</b>
<b>Documents</b>	6	4	7	7	1	5
<b>Groups</b>	3	7	NA	NA	NA	NA
<b>Sites</b>	2	8	2	12	1	5
<b>Chat</b>	NA	NA	6	8	NA	NA
<b>Week 5</b>						
	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>No</b>
<b>Helped Learning</b>	8	0	12	2	4	1
	1 SAME					
<b>Hindered Learning</b>	1	9	2	12	5	1
<b>Week 10-13</b>						
	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>No</b>
<b>Helped Learning</b>	6	3	10	1	7	0
		1 NEITHER				
<b>Hindered Learning</b>	1	8	1	10	1	1
<b>* Voluntary participation accounts for variance in # of respondents</b>						

## 4. Conclusions

This educational design research case aimed to achieve two overarching goals. The first: How do we design an innovative open source intervention using Google Applications to model the effective use of technology integration to support individual and peer learning?

The research sub-questions that guided this were:

1. What is the process of creating a higher education course utilizing Google Applications?
2. What perceptions do adult learners have regarding the functions of Google Applications?

The second goal was: What are the characteristics of a course that will allow learners to embrace the use of an open access practical learning management system while supporting learner and teacher course content knowledge acquisition? The research sub-questions that guided this were:

3. What are the perceptions of learners and teachers regarding the use/functions of the course?
4. Based on learner and instructor feedback, what course alterations are recommended?

Data from 32 participants, three graduate students and one instructor was collected over a 45-week period of time during the three phases of this educational design research study. Applying this research methodology allowed for the extended amount of time needed for significant feedback to occur, reflection on that feedback and critical appropriate redesigns to come to fruition.

Although these are the yields of this particular study, these findings may assist colleagues in the design and development of courses utilizing Google Applications. The process of creating and revising a higher education course utilizing Google Applications included the instructor acquiring the knowledge and skills in both face-to-face and distance education competencies. As an instructor for primarily face-to-face courses, the instructor wanted to maintain the level of interaction she was accustomed to while using an easy to maneuver learning management system. Incorporating high levels of interactions between peers/instructor and individual student/ instructor were critical to the success of the course. The different applications in Google met those two requirements. Conducting formative evaluation with the students throughout the course in order to make adjustments was critical in the process. For example, repeatedly seeing the frustration with Google Groups was not exclusive to this course, students often express frustration with discussion boards in online environments. During this study however, we had the technology and the time to solve this design issue for Phase II and refine it during Phase III. The addition of Google Applications, also implemented during Phase II was refined in Phase III with the addition of the editing job aid for Peer Group work. The instructor documenting the successes/failures throughout the course was also critical in the process of creating a course utilizing Google Applications. The instructor observed and documented her thoughts on the students throughout the semester and reading their minor frustrations with the learning curve of Google Applications did not believe the frustration was solely the use of the Applications but rather a need to communicate more frequently with her. She decided to add the Weekly Reflection Journals in Phase II and the response was so positive, they were kept during Phase III. This was also true with the Google Chat online office hours. Documenting and making any alterations to the design and implementation of the next course offering was the final critical component in the process of creating this course. Applying educational design research to this case allowed these finite details to emerge strengthening the course design and delivery and ultimately student learning and their experience. These lessons are now being applied to other courses in the program.

As stated in the findings section of each phase, students perceived the Google Applications as easy to access and use. They preferred to have all of the information needed for the course in one location and found the interactions with the instructor and peers in the class extremely helpful.

Students overall perceived Google Applications as helpful in their learning a new learning management system. Table 4 illustrates the yields of the study that may assist colleagues and practitioners when designing online courses using Google Applications.

Table 4: Summary of web-based survey data from three phases

<b>Literature used for initial course design</b>		
<p>Web 2.0 Tools in education allow for:</p> <ul style="list-style-type: none"> <li>imaginative course design (Mason &amp; Rennie, 2008)</li> <li>successful collaborative online learning experience (Mason &amp; Rennie, 2008)</li> <li>professor to model use of a tool for professional practice (Tracey &amp; Unger, 2011)</li> <li>increased student motivation (Tracey &amp; Unger, 2011).</li> </ul> <p>Teaching at a distance requires instructors to:</p> <ul style="list-style-type: none"> <li>build competencies involving student activities at field sites, knowledge of the distance learning field, design of study guides correlated with the technology, and graphic design and visual thinking (Crys, 1997)</li> <li>consider new paradigms for teaching (Easton, 2003), and model appropriate use of communication tools (Unger &amp; Tracey, 2012).</li> </ul> <p>Google Applications:</p> <ul style="list-style-type: none"> <li>are free and customizable web-based tools (Google, 2010)</li> <li>provide platform for educators and students to communicate and collaborate to learn more effectively (Google, 2010)</li> <li>provide students with 21<sup>st</sup> century skills (Google, 2010).</li> </ul>		
<b>Phase I: Winter 2011</b>	<b>Findings</b>	<b>Course changes</b>
	<ul style="list-style-type: none"> <li>Students perceived that Google Applications helped them to learn the course content</li> <li>Students had positive perceptions of the Google Applications, because they were: <ul style="list-style-type: none"> <li>easy to use</li> <li>beneficial for collaborating with others</li> <li>allowed for instant feedback</li> <li>tools that can be used in their own professional practice</li> </ul> </li> <li>Some students experienced compatibility issues between Microsoft Office and Google Applications</li> <li>Students wanted all of the tools accessible from one location</li> <li>Students suggested that the instructor provide Google Application job aids at the beginning of the course</li> <li>Students requested a better way for facilitating online discussions</li> <li>Students like that the instructor incorporated a variety of communication methods</li> </ul>	<p>Distribute Google Application job aids prior to the beginning of the course</p> <p>Create centralized location for course content</p> <ul style="list-style-type: none"> <li>Syllabus created in Google Documents and embedded into the course site provided one location for students to look for course updates</li> <li>Reorganization of the site by weeks, which included student outcomes, instructional materials, and assignments</li> </ul> <p>Implement different method for facilitating asynchronous online discussions</p> <ul style="list-style-type: none"> <li>Google Groups for discussions were removed and replaced with small peer groups of 4, which answered questions and worked on peer assignments in Google Documents. Instructor had access to each group's Google Document to contribute to their discussions and guide their learning</li> </ul>

Table 4: Summary of web-based survey data from three phases (continued)

Phase I: Winter 2011	Findings	Course changes
		<ul style="list-style-type: none"> <li>• Added weekly reflection journal stored in a Google Document for individualized communication between student and instructor</li> <li>• Added online office hours (17hrs per week) where students could access the instructor through Google Chat</li> </ul>
Phase II: Fall 2012	Findings	Course changes
	<ul style="list-style-type: none"> <li>• Students perceived that Google Applications helped them to learn the course content</li> <li>• Students had positive perceptions of the Google Applications, because they were:               <ul style="list-style-type: none"> <li>- easy to use</li> <li>- beneficial for collaborating with others</li> </ul> </li> <li>• Students preferred Google Applications to Blackboard because it was accessible via any computer or mobile device</li> <li>• Students liked the weekly communication with the instructor through the individual reflection journals, because it helped them understand the course content</li> <li>• Students did not like working in Google Documents for the peer group assignments, and recommended the documents be broken down into shorter documents</li> <li>• Students perceived the content was organized in a logical manner and liked having it in one location</li> <li>• Students liked using Google Chat for communicating</li> <li>• Students recommended a one column homepage so the most recent information was always at the top</li> </ul>	<p>Course homepage was changed into a single column</p> <p>Peer documents were broken into shorter documents for easier navigation</p> <ul style="list-style-type: none"> <li>• Peer group Google Documents were created for each discussion week to resolve the issue with the document being too long and hard to navigate</li> </ul> <p>Include instruction on the revision history function in Google Documents</p> <ul style="list-style-type: none"> <li>• Job aid was created and provided with other Google Application job aids at the beginning of the course</li> </ul>

Table 4: Summary of web-based survey data from three phases (continued)

Phase III: Winter 2012	Findings	Course changes
	<ul style="list-style-type: none"> <li>• Students perceived that Google Applications helped them to learn the course content</li> <li>• Students had positive perceptions of the Google Applications, because they were:               <ul style="list-style-type: none"> <li>- easy to use</li> <li>- beneficial for collaborating with others</li> <li>- allowed for instant feedback</li> </ul> </li> <li>• Students were receptive to working in Google Documents for the peer group assignments</li> <li>• Students liked using Google Chat for communicating</li> <li>• Students suggesting including some video webinar session</li> <li>• Students wanted grades to be accessible through Google instead of having to access them through Blackboard</li> </ul>	<p>Phase III was the end of the study and no other course redesigns were completed at this time.</p>

This educational design case study focused on enhancing the communication process for collaborating and disseminating knowledge and skills through a free online technology tool: Google Applications. The findings and personal experience from this case study may be beneficial to others in their own practice. If so, having easy and accessible access to these Google Applications provides instructional designers and educators the opportunity to immediately put into practice instructional strategies and Applications they can actually use. This study also provided details for best practices for utilizing Google Applications to enhance the teaching and learning process across any discipline.

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## Towards a Competence-based Curriculum for a New Faculty of Education of the Eduardo Mondlane University, Mozambique: A Reconstructive Study

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# 48. Towards a competence-based curriculum for a new faculty of Education of the Eduardo Mondlane University, Mozambique: A reconstructive study

Wim Kouwenhoven

## Abstract

*This case involves the reconstructive study of the design, development and implementation of a competence-based curriculum at Masters level for a new Faculty of Education at the Eduardo Mondlane University of Mozambique. The curriculum development took place in the context of a Dutch funded project in which the VU University Amsterdam, University of Twente and University of Groningen participated. A reconstructive educational design approach was chosen, that is, a retrospective analysis of all events leading to the articulation and specification of design principles and new (design) knowledge. The design, development and implementation of the curriculum was “reconstructed” and analysed using three different lenses: substantive aspects (the product), technical professional aspects (procedures and principles), and socio-political aspects (actors and factors). As a basis for the research questions in the study an evaluation model was developed with hypotheses about characteristics of the interventions and their effect. The conceptual basis for a competence-based approach was worked out in an elaborate literature review. The design phase (including the context analysis), the development and the implementation phase were reconstructed and analysed through the three lenses mentioned above. The study resulted in a number of design guidelines and recommendations for further development and research. A reflection on the role of the researcher who was also designer (and educational adviser) ends this case.*

## 1. Introduction

Mozambique started immediately after its independence in 1975 with building its education system. The training of teachers got priority and the Faculty of Education of the Eduardo Mondlane University (UEM) in Maputo was primarily involved with teacher training. This teacher training moved in the next decade to a separate Pedagogical University (UP) and the Faculty of Education was closed “temporarily” in 1985. Because the need for educationalists with an academic background increased after the end of the civil war in 1992, the University Council of the UEM decided, in 1999, to re-open the Faculty of Education. A proposal for aims, activities and structure of the ‘new’ Faculty was drawn up. This included the start of three post-graduate programmes in education: Master’s programmes in Curriculum and Instruction Development, in Adult Education, and in Science and Mathematics Education. The programmes should have a competence-based approach. An “Installation Committee” was established in 1999 to design and develop the programmes. The author worked at that time as an education adviser in the Academic Development Centre of the UEM, and was, in that capacity, invited to join the Installation Committee. In addition to his role as education adviser, he was requested to take a leading role, during the initial period of the Installation Committee, in the process of curriculum design and development for the new Master programmes.

The design, development and implementation process was supported in a Dutch funded project in which the VU University Amsterdam, University of Twente and University of Groningen participated.

The curriculum design and development resulted, in August 2001, in the start of the above mentioned post-graduate programmes, all three with the intended competence-based approach. Given the innovative character of establishing these competence-based programmes in the context of a developing country, the author decided - in consultation and collaboration with an expert of the University of Twente and with approval of the Installation Committee - to describe and analyse this process as an (accompanying) design research project.

In retrospect the author had a triple role in establishing the new faculty, that is, as curriculum designer, education adviser and above all as researcher. The research role resulted in a PhD thesis (Kouwenhoven, 2003).

In this chapter the reconstructive approach for the study of this curriculum development project is explained. A model involving evaluation hypotheses is introduced as a framework for the research questions. The conceptual framework that was the basis of the design and development of a competence-based curriculum is summarised in the next section. This is followed by a description of the research done during and after the design, development and implementation phases. The chapter finishes with brief observations about the yield of the research project and some reflections.

## 2. Research approach

### A reconstructive approach in educational design research

The design, development and implementation of a competence-based curriculum in the Faculty of Education were seen as an educational intervention, aimed at alleviating the problem of, in its most general form, the poor quality and effectiveness of the education system in Mozambique. The fact that the curriculum development process took place in a new context, starting with nothing but ideas, provided a unique opportunity to monitor and describe closely the curriculum development process.

As mentioned above, the author had a triple role, of researcher, designer/developer and educational adviser. These roles were changing over time as is summarised in Table 1.

*Table 1: Researcher's roles in the curriculum development for the new the Faculty of Education*

<b>Researcher's Roles</b>	<b>Designer</b>	<b>Researcher</b>	<b>Education adviser</b>
<b>Phases in Curriculum development</b>			
Design (including Front-end analysis)	+	formative reconstructive	+
Development	±	formative reconstructive	±
Implementation	-	formative reconstructive	±

*Legend:* '+' : full control or full participation  
 '-' : no control or no participation  
 '±' : partial control and participation  
 A smaller font size indicates a diminishing role.

In the "Installation Committee", the researcher had initially a leading role as curriculum designer, feeding the other members with suggestions and proposals for both the process of curriculum development, and how a competence based curriculum for the respective Master programmes should look like. However, over time design decisions were increasingly taken out of the hands of the 'researcher as designer' and got diffused and diluted in the higher and middle level leadership as in its early days the new faculty had not yet a clear management structure. As a member of the "Installation Committee" for the new faculty (pertaining to his role as educational adviser), that guided the design and development of the curriculum, the researcher was fully involved in all decisions about the establishment of the Faculty of Education during the design phase and, to some extent, during the development phase of the curriculum. The researcher was not a member of the staff of the new Faculty of Education (because he belonged to UEM's Centre for Academic Development), so he was basically not involved in the implementation of the curriculum.

In brief, the research by the author started in a 'formative' mode involving research activities "...aimed at optimization of the quality of the intervention as well as testing design principles" (Van den Akker, 1999, p. 6). However the major part of his research may be characterised as reconstructive. In reconstructive educational design research the design, development and (sometimes) implementation of educational interventions is "reconstructed" and analysed using different lenses. Van den Akker sees the aim of reconstructive research as the articulation and specification of design principles, while Visscher-Voerman and Gustafson (2004) speak of the creation of new design knowledge. Cobb, Confrey, DiSessa, Lehrer, R., & Schauble (2003) use the term 'retrospective analysis' in which the "...historical or retrospective explanation ... provides a trustworthy account of the process whereby a series of events ... can be seen as part of an emergent and potentially reproducible pattern". (p.12). The designer (and formative researcher) role, although diminishing during the design and development process remained and formative evaluation took place aimed at products (Masters programmes) that would as best as possible reflect the "intended curriculum".

Based on the curriculum typology of Goodlad, Klein and Tye (1979), the study investigated retrospectively various phases in the design and development of a competence-based curriculum for the Faculty of Education. The design of the *intended curriculum* was reconstructed and analysed, followed by the development phase (*formal curriculum*), and the implementation of the curriculum (*operational and experiential curriculum*). In this study the 'how' and 'why' of design, development and implementation events were described and explained from three view points, as described in the next paragraph. So, exploration and explanation were both used in this reconstructive design research approach

### **Research questions for three phases**

The need for academically trained education professionals formed the context of the question: "How could the education and training of education professionals with a competence-based approach contribute to improving the quality and efficacy of the education system of Mozambique?"

After this question, referring to the impact (the long-term effect) of educational interventions, had been discussed and analysed in the early stages of the design phase, the main problem statement for the research project was formulated as:

"This study is to determine what are the characteristics of an effective competence-based curriculum for the Faculty of Education at UEM and how such a curriculum should be designed, developed and implemented".

This problem statement refers to the more immediate outcomes. A reconstructive approach was used to answer the questions on product and process.



Three sets of research questions were derived from the main problem statement. They guided the data collection and analysis during the design phase, the development phase and during the implementation phase of the curriculum.

The research questions for each phase are representative for three points of view or lenses through which the curriculum development process can be analysed (cf. Van den Akker, 2003).

The first lens refers to substantive aspects of the curriculum design and development. It concerns questions about the curriculum as product. The second lens is the technical professional point of view. It deals with the procedures and principles followed in the design and development process. The last research question represents a socio-political lens and involves the players and circumstances. Table 2 provides an overview of phases and lenses and research questions.

Table 2: An overview of research questions for the study

	<b>Substantive aspects</b>	<b>Technical/professional aspects</b>	<b>Socio-political aspects</b>
<b>Design phase</b> <ul style="list-style-type: none"> <li>• Context/needs/front-end analysis</li> <li>• Design</li> </ul>	<ul style="list-style-type: none"> <li>• Why should the curriculum for the Faculty of Education be competence-based?</li> <li>• What might be the characteristics of a competence-based curriculum that may result in competent educational professionals for the Mozambican society?</li> </ul>	<p>What procedures and principles have been followed during the design of a competence-based curriculum for the Faculty of Education?</p>	<p>What role did the various actors play in the curriculum design and development process influence and what conditions and activities further influenced the design and development process?</p>
<b>Development phase</b>	<p>What are the characteristics of a competence-based curriculum in the context of the Faculty of Education at UEM?</p>	<p>What procedures and principles have been followed during the development of a competence-based curriculum for the Faculty of Education?</p>	<p>What conditions and activities influenced the development of a competence-based curriculum for the Faculty of Education? What was the influence of various actors?</p>
<b>Implementation phase</b>	<p>What are the characteristics of the Implemented competence-based curriculum in the context of the Faculty of Education at UEM, as operationalised by the staff and experienced by the students?</p>	<p>What procedures and principles have been followed during the implementation of a competence-based curriculum for the Faculty of Education at UEM?</p>	<p>What conditions and activities have influenced the implementation of a competence-based curriculum for the Faculty of Education at UEM? What was the influence of various actors?</p>

The table shows that questions on the substantive aspects were directed at different products during the three phases. The questions on technical/professional and socio-political aspects could be phrased in similar terms, without expecting similar answers.

### **A model involving evaluation hypotheses**

For the evaluation of the design and development of Master's programmes at the Faculty of Education at UEM a model was used, adapted from the Rossi, Freeman and Lipsey model (Rossi et al., 1999). Their intervention model describes the reconstruction and analysis as a 'virtual experiment' in which hypotheses play a role as propositions. The mental exercise aimed at formulating the hypotheses went along the following lines: Educational programmes are conceptualised as interventions that respond to a certain need or solve a certain problem (have a certain impact).

In order to have an impact the programmes should have certain characteristics. In the case of the Faculty of Education the curriculum should be sufficiently competence-based.

In order to have a curriculum with the required characteristics certain principles and procedures of design and development should be followed.

A curriculum with the required characteristics should be implemented along certain recommended procedural guidelines, in order to result in immediate outcomes that would in the end lead to the desired impact and answer the need.

The model, presented in figure 1, describes the evaluation taking place during the design, development and implementation of an intervention. The question why the programme or intervention is necessary can be formulated as a '*causal hypothesis*', relating the programme's actions to achieve the intended social benefits. In other words, the causal hypothesis relates the intervention to the (social/educational) problem that it intends to solve, or states the cause of the problem in terms of the lack of intended social benefits.

A difference with the original model of Rossi et al. (1999), apart from using a different terminology, is the addition of the design and development of the intervention as a separate step. The *development hypothesis* links the design and development of the curriculum (as product), together with the implementation of the curriculum, to the (immediate) outcomes of the intervention. The development hypothesis, therefore, includes the assumptions and expectations about the intervention, expressed through (product) characteristics C1, C2, ...Cm, or through the *intervention hypothesis*; the assumptions and expectations about the design and development process, expected to lead to the intervention with the intended characteristics, expressed through procedural guidelines D1, D2, ...Dk, or through the *design hypothesis*; and the assumptions and expectations about the implementation process, expressed through procedural guidelines P1, P2, ...Pn, or through the *implementation hypothesis*.

Finally, the *impact hypothesis* links the immediate outcomes of the programme to the final social benefits/change (distant outcomes). The impact hypothesis can only be verified after the programme has been running for some time. Longitudinal research may be used in verifying the impact hypothesis.

The model presented in Figure 1 offers the opportunity to explain why the programme or intervention led or did not lead to the immediate outcomes as expected. Rossi et al. (1999) talk about *implementation failure* and *theory failure*. When the immediate outcomes are not as they were expected to be, the intervention could have the intended characteristics but is not implemented as intended (implementation failure). It could have the intended characteristics and be implemented as intended, but still not have the intended immediate outcomes (theory failure). Another possibility is that the characteristics of the intervention are not as intended because of deviations in the intended design and development, which could be called *development failure*.

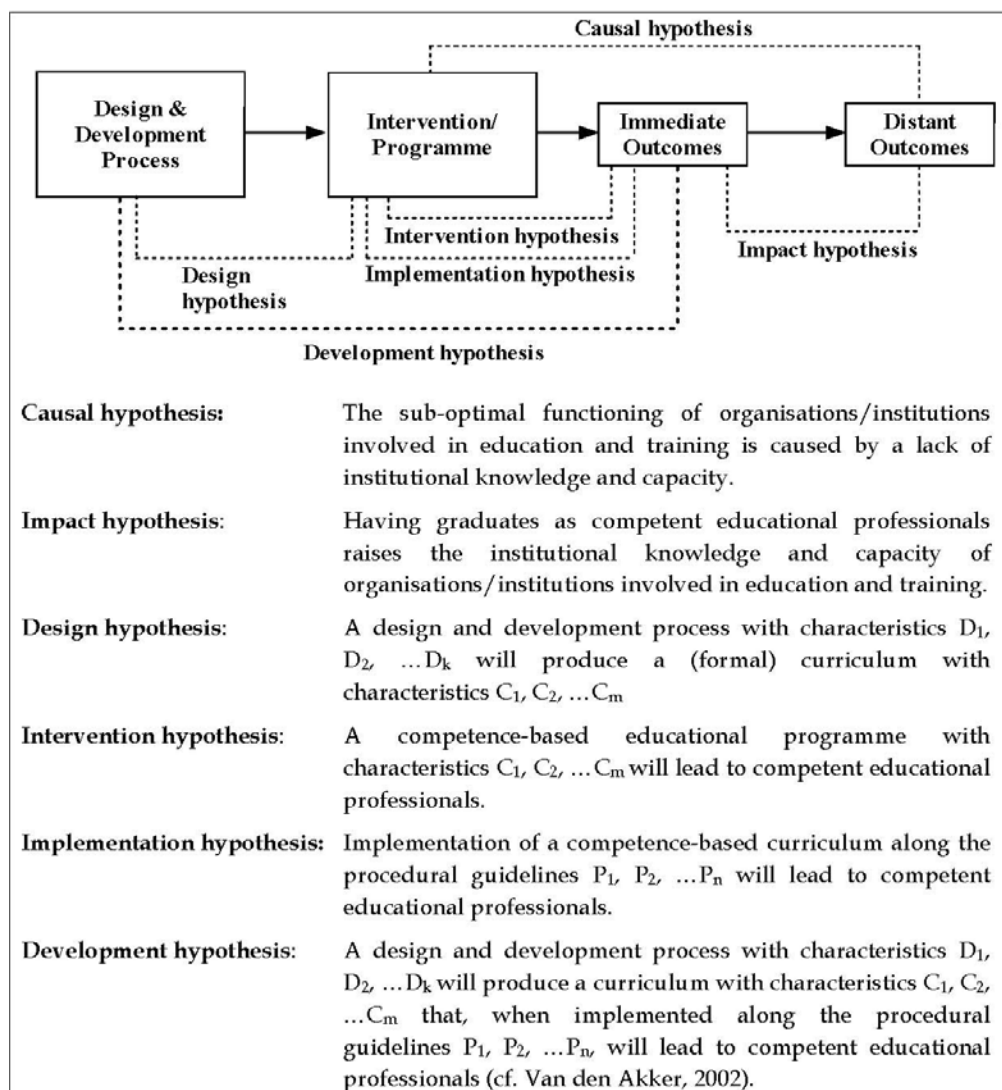


Figure 1: Evaluation hypotheses in the design, development and implementation of masters programmes in the faculty of Education at UEM

### 3. A summary of the research activities

It is possible to identify in the evaluation model of Figure 1 the various stages of the curriculum, as described by Goodlad et al. (1979). Table 3 summarises the various stages of the design and development process, the evaluation questions and the research activities carried out during the project.

Table 3: An overview of the research on the curriculum design and development in the Faculty of Education at UEM

Evaluation of the educational programme	Design Research		Curriculum typology	Research activities
	Substantive aspects	Process aspects		
<b>Causal hypothesis</b> The sub-optimal functioning of organisations/institutions involved in education and training is caused by a lack of institutional knowledge and capacity	<b>What is the problem?</b>			Needs assessment Study of documents
	Context/front-end analysis Needs analysis			
<b>Impact hypothesis</b> Producing graduates that are competent educational professionals leads to better functioning organisations				Not addressed in study
<b>Intervention hypothesis</b> A competence-based educational programme with characteristics C1, C2, ...Cm will lead to competent educational professionals.	<b>What is the solution?</b>		<b>Intended curriculum</b>	Workshops with design team (brainstorm, round table) Questionnaires to Mozambican and Dutch staff Interviews Logbook by researcher
	What might be the characteristics of a competence-based curriculum that results in competent educational professionals for the Mozambican society? Why should a competence-based curriculum be developed for the Faculty of Education?	What procedures and principles have been followed during the design of a competence-based curriculum for the Faculty of Education? What role did the various actors play in the curriculum design and what conditions and activities further influenced the design process?		
	What is the quality of the graduates of the competence-based curriculum?		<b>Assessed curriculum</b>	Not addressed in study

Table 3: An overview of the research on the curriculum design and development in the Faculty of Education at UEM (continued)

<p><b>Design hypothesis</b> A design and development process with characteristics D1, D2, ...Dk will produce a curriculum with characteristics C1, C2, ...Cn</p>	<p><b>What does the solution look like?</b></p>		<p><b>Formal curriculum</b></p>	<p>Questionnaires to Mozambican and Dutch staff Interviews Logbook by researcher</p>
	<p>What are the characteristics of a competence-based curriculum in the context of the Faculty of Education at UEM?</p>	<p>What procedures and principles have been followed during the development of a competence-based curriculum at the Faculty of Education at UEM? What role did the various actors play in the curriculum development and what conditions and activities have influenced the development of a competence-based curriculum for the Faculty of Education at UEM?</p>		
<p><b>Implementation hypothesis</b> Implementation of a competence-based curriculum along the procedural guidelines P1, P2, ...Pn will lead to competent educational professionals</p>	<p><b>How should the solution be implemented?</b></p>		<p><b>Perceived curriculum and Operational curriculum</b></p> <p><b>Experiential curriculum</b></p>	<p>Self assessment by students on generic competencies Evaluation of courses Interviews with students Class observations Questionnaires to staff and students Interviews with staff Logbook by researcher</p>
	<p>What are the characteristics of the implemented competence-based curriculum in the context of the Faculty of Education at UEM, as operationalised by the staff and experienced by the students?</p>	<p>What procedures and principles have been followed during the implementation of a competence-based curriculum for the Faculty of Education at UEM? What role did the various actors play in the implementation of the curriculum and what conditions and activities have further influenced the implementation of a competence-based curriculum for the Faculty of Education at UEM?</p>		

Table 3: An overview of the research on the curriculum design and development in the Faculty of Education at UEM (continued)

	Does the solution work?		Assessed curriculum	Not addressed in study
	What is the quality of the graduates of the competence-based curriculum?			
<b>Development hypothesis</b> A design and development process with characteristics D1, D2, ...Dk will lead to a curriculum with characteristics C1, C2, ...Cm and the implementation along the procedural guidelines P1, P2, ...Pn will lead to a 'functional' competence-based curriculum.	In what way (to what extent) can the development process and the resulting curriculum be transferred to higher education in countries comparable to Mozambique?			

As can be seen from Table 3 the collection of data accompanied the various stages of the curriculum development process.

Table 4 gives a timeline of the major events in the curriculum development process. The research project covered only part of the implementation, because the author's contract at the university had finished.

During the prologue a literature study started on competence-based education. The concepts that were the basis of the curriculum development process are outlined in section 4. The subsequent phases are described in section 5.

Table 4: The curriculum development process: events and timing

Time	Event	Phase
<b>Initial steps towards the re-opening of the Faculty of Education</b>		
May 1997 to December 1999	Activities of working group and first commission	Prologue
January to July 1999	A beginning of co-operation with Dutch Universities	
January to July 1999	Elaborating a first official document on the re-opening of the Faculty of Education	
July to December 1999	From the appointment of the Installation Commission to the first major planning workshop	

Table 4: The curriculum development process: events and timing (continued)

Time	Event	Phase
<b>Context and needs analysis</b>		
February 2000	First workshop on planning the curriculum development process	Front-end analysis
February to July 2000	Preparation of a needs Assessment	
July to December 2000	Needs assessment	
<b>Towards an intended curriculum</b>		
December 2000	Workshop on translating the needs assessment results into design guidelines	Design
February 2001	Workshop on intended curriculum and further planning of curriculum development	
<b>Towards a formal curriculum</b>		
February-July 2001	Development of curriculum for three Masters programmes	Development
July 2001	Approval of formal curriculum by university council	
<b>The curriculum in operation</b>		
August 2001 to May 2002	Implementation of the common core in three post-graduate programmes	Implementation

## 4. A conceptual framework

### Competence-based education

In order to answer the question on the characteristics of a competence-based curriculum in the context of the Faculty of Education at UEM, a literature study was carried out. Guiding questions were how competence and competencies could be conceptualised and what would be effective ways to acquire and develop competence through Higher Education.

Developments in science, society and economy form the context for the (renewed) interest in competence and competence-based education and training. The acquisition of knowledge in itself is not anymore the major aim of education and training, but the application of the acquired knowledge (Gibbons, 1998). This is also seen in the diminishing gap between the vocational and general aspects of education (Teichler, 1998).

The dimensions of the competence concept and related terms and concepts were partly based on an article by Stoof, Martens, Van Merriënboer and Bastiaens (2002), in which a pragmatic solution is proposed for defining competence. Attention was paid as well to the literature that represents criticism on the competence movement. A competence model was developed, based on the ideas of Paul Hager (Hager & Gonczi, 1996) of an integrated, holistic approach to competence and competence-based education and training (see figure 2)

Point of departure for the model is the question: "What drives a satisfactory or excellent performance?"

The model describes what 'goes on in the head' (i.e. processing at cognitive level) when a task is realised. From this model competency is deduced as the ability to process tasks in an intentional way. A professional performs in his/her work a large number of tasks that can be grouped into 'key occupational tasks' or roles.

The realisation (performance) of tasks implies 'intentional actions', activities that are consciously planned, monitored and regulated and that involve certain attributes (knowledge, skills, attitudes) and personal characteristics of the professional. Knowledge, skills and attitudes are utilised in an integrated way, although they may be used in varying degrees, depending on the (occupational) task or task component. In order to perform (key) tasks the professional should be able to 'select' and use the appropriate knowledge, skills and attitudes, that is, process them and come to deliberate actions, aimed at realising the task. The mental processing of a task or a problem requires certain cognitive monitoring and regulation activities, labelled 'meta-cognition'. An example is 'situational understanding' (professionals take account of the varying contexts in which they are operating and are able to transfer, that is, select and apply the necessary attributes in new contexts). In the model, presented in Figure 2 the task related context (where and how the task is 'situated') is perceived and processed by situational understanding. The personal context involves (amongst others) emotional, physical factors that directly influence the professional as a person. The personal characteristics determine to what extent these positive or negative factors will influence the processing of the task. Reflection on the outcomes provides feedback to the practitioner, leading, if necessary, to additional intentional actions.

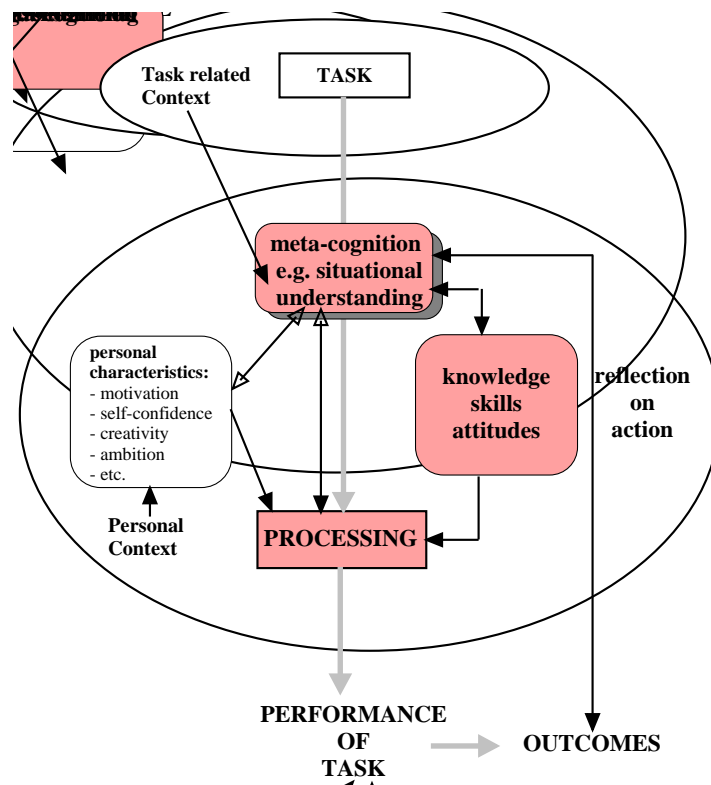


Figure 2: A model of competency through cognitive aspects of task performance

Competency and competence can be deduced from the model and be defined as follows (Kouwenhoven, 2009): *Competency* is the capability to choose and use (apply) an integrated combination of knowledge, skills and attitudes with the intention to realise a task in a certain



context, while personal characteristics such as motivation, self-confidence, willpower are part of that context.

Attention was paid to 'generic competencies' (e.g. Rychen & Salganik, 2000) and their role in general and vocational higher education. The relation between competence, key competencies and constituting (domain specific and generic) competencies was given in a model for competence-based curriculum development (see Figure 3). An illustration of how these concepts were used in practice for the Masters programme in Curriculum and Instruction Development that was developed for the new Faculty of Education at UEM is given in Table 5.

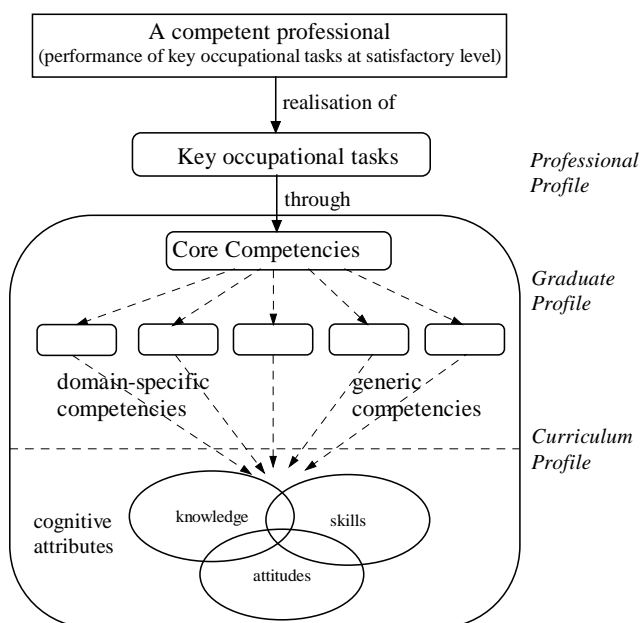


Figure 3: Competence-based curriculum development

Characteristics of competence-based education were discussed as well as the question why competence-based education could offer a contribution to the education of students/graduates that are well prepared to answer to the needs and demands of society, or, more specifically, the education sector in Mozambique. Based on a study on CBET in Dutch schools (Van der Sanden, Streumer, Doornekamp, & Teurlings., 2001) a checklist was presented for the “screening” of a competence-based curriculum and related courses or modules.

Table 5: Profiles for a Master's programme in Curriculum and Instruction Development

<p><b>Professional profile</b></p> <p><b>Key tasks in four areas:</b></p> <p><b>A. Design and development of curricula, including materials</b> For example: Design of education and training programmes, including seminars and workshops</p> <p><b>B. Applied research and evaluation</b> For example: Realisation of needs assessments</p> <p><b>C. Dissemination and implementation</b> For example: Efficient implementation of innovations in the domain of the curriculum</p> <p><b>D. Planning and management</b> For example: Planning and management of education projects</p>
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Table 5: Profiles for a Master's programme in Curriculum and Instruction Development  
(continued)

<p><b>Graduate Profile</b></p> <p><b>Key competencies:</b></p> <p>A. The ability to design and develop curricula, including materials</p> <p>B. The ability to do applied research and evaluation</p> <p>C. The ability to dissemination and implement educational interventions</p> <p>D. The ability to plan and manage educational interventions</p>
<p><b>Curriculum profile</b></p> <p><b>Some domain specific competencies:</b></p> <ul style="list-style-type: none"> <li>• The ability to advise and assist teams in the elaboration of teaching materials</li> <li>• The ability to evaluate curricula/programmes/courses/disciplines/modules/learning materials</li> </ul> <p><b>Some generic competencies:</b></p> <ul style="list-style-type: none"> <li>• The ability to recognise critical incidents/problematic situations in the professional practice as design problems and design &amp; develop 'doable' solutions, applying methodological approaches</li> <li>• The ability to use information and communication technology (including multi-media) to enhance learning and to enhance personal and professional productivity</li> </ul>

## 5. Reconstruction of the design, development and implementation phases

### Front-end analysis

A needs assessment played an important role in the front-end analysis that preceded the formulation of the first design proposals and subsequent development activities. The needs assessment covered three areas, namely the need for educational programmes in the Faculty of Education at the UEM, the description of professional profiles that form the basis for graduate profiles and the organisation of the curriculum in the Faculty (cf. Kouwenhoven, Howie & Plomp, 2003). The first area related to the first research question given in Table 2: "Why should the curriculum for the Faculty of Education be competence-based?" The other two areas provided answers that formed the start of the design phase, phrased in Table 2 as: "What might be the characteristics of a competence-based curriculum that may result in competent educational professionals for the Mozambican society?"

The needs assessment involved a 'purposeful' sample of 61 informants with supposed knowledge about the professional aspects of Science and Mathematics Education or Curriculum and Instruction Development. Results of a cluster analysis of rating key occupational tasks suggested important competencies to be acquired in the various Masters programmes. The low number of respondents, although representing a purposeful sample, led to a cautious interpretation of the results of the cluster analysis. It was concluded as well that the respondents did not have a clear idea of recent developments in the professional area or could not oversee the whole area. Therefore, additional input of expertise by local staff and counterparts from Dutch cooperating universities was needed.

### Design

The assignment to the design team (the Installation Committee) was to develop a competence-based curriculum for a new Faculty of Education. From a procedural (technical/professional) point of view a communicative approach (cf. Visscher-Voerman, Gustafson, & Plomp, 1999)

was applied, where a constant deliberation with stakeholders was taking place in order to get consensus on the characteristics of 'the problem' and on the intervention needed to solve the problem.

Two groups of actors were important in this respect. The first one was the group of stakeholders outside the UEM (education officers at provincial and district level, managers of educational institutions, teachers). They proved important in the early stage of the curriculum design in providing feedback to initial ideas about the concept of a competence-based curriculum. Using the terminology of Walker (1990) a first design principle was, therefore, that it is important to have a group of stakeholders/participants that is large and diverse enough to create a 'platform of ideas' leading to the design of a 'functional' curriculum. Functional implies in the first place external consistency, that is, the coherence of the perceptions of a curriculum between the actors (designer/developer, management, academic staff, and students). The input of stakeholders also contributes to internal consistency of the curriculum (cf. Kessels & Plomp, 1999). This is the coherence (the internal logic) of all elements of a curriculum, as pictured in the metaphor of spider web with ten radii representing ten essential elements of a curriculum (Van den Akker, 2003). The second important group of actors was formed by the staff. Although small in number, most staff could devote all their time to the curriculum development process and did so with great motivation and enthusiasm. Joint activities of staff in a Study Group created conditions for more learning and development in the area of curriculum development and competence-based education. A second design principle was, therefore, that it is important to involve all staff in the design and development process and create during the process opportunities for learning and development (cf. Kessels, 2000). This implied setting up a functional communication network, linking all the actors involved in the curriculum development process.

From a socio-political point of view the influence of the UEM leadership, although in the background, was strong in steering the work of the appointed commissions towards a re-opening of the faculty. The Dutch partner universities, brought in their expertise on curriculum development and pushed the idea of competence-based education in the future faculty forward with great energy.

After some initial feelings of discontent, resolved through the creation of the Working Group on Curriculum Development, the role of the designer-researcher was accepted and he continued to initiate new design and development activities. In this initial stage of the curriculum development process the researcher was also fully involved as designer and as member of the Installation Committee, playing the roles of 'dedicated participant' and 'critical outsider' (cf. Thijs, 1999).

### **Towards a formal curriculum, the development phase**

Three research questions were used to analyse product and process in the development phase. The first question is product-related and reads: "*What are the characteristics of a competence-based curriculum in the context of the Faculty of Education at UEM?*" The curriculum development process resulted, at the end of the development phase, in a formal curriculum represented by a curriculum document (UEM, 2001) and some course outlines. In a condensed form the characteristics of the intended competence-based curriculum were formulated as:

- A competence-based curriculum (CBC) is based on the future occupational practice of the graduate.
- Curriculum development is based on the elaboration of profiles and identification of competencies.
- Curriculum content, learning environment and assessment depend on the identified competencies (principle of backwards designing).
- Learning environments and assessment are focussed on competencies and aligned.

- A CBC is learner-centred and the learning process is central.
- In a CBC the role of the teacher is that of a 'cognitive guide'.
- A CBC has a constructivist approach.
- A CBC includes the development of generic competencies.

Based on the literature study on competence-based education, a number of questions or criteria had been formulated to check the competence-based characteristics of the formal curriculum. In terms of Nieveen (2007) this could be seen as a screening on consistency, although in a reconstructive way. The formal curriculum, represented in the curriculum document (UEM, 2001), 'scored' as sufficient on a number of aspects while other aspects had been insufficiently addressed. Two of these included aspects that are often perceived as difficult in competence-based curriculum development:

- The lack of explication on how authentic learning situations could be created in a variety of contexts, and how authentic assessment could be done.
  - Insufficient addressing the integration of generic competencies in courses or modules.
- Although these aspects were noted, time pressure and lack of human resources prevented seriously addressing these aspects. Analysis of ten curriculum aspects in the four outlines of core courses showed that two of them had a sufficient competence-based character.

The curriculum development process was reconstructed and analysed through a technical-professional and a socio-political lens. The analysis from a technical-professional point of view was guided by the research question: "*What procedures and principles have been followed during the development of a competence-based curriculum for the Faculty of Education at UEM?*" The curriculum of the Masters programmes had internal and external consistency. Internal consistency was aimed for through the alignment of all aspects of the curriculum, including the results of the needs assessment, the formulation of professional and graduate profiles, the choice of content, and the design of learning environments (cf. Kessels, 1999). External consistency was maintained throughout the design and development process through repeatedly reconfirming decisions that had been taken already on curriculum aspects and extensively discussing new steps with all staff. Throughout the design and development process workshops and meetings were organised regularly, focusing on the development of the curriculum for the new Faculty of Education.

Curriculum development meant also staff development. Mozambican staff could be characterised in their involvement in the implementation of a competence-based curriculum as on their way from the mechanical stage (in terms of the model of De Feiter, Vonk, & Van den Akker, 1995) to the routine stage of development.

The socio-political aspects of the curriculum development process were analysed (mainly through study of policy documents, reports of meetings and workshops, observations and the researcher's logbook) based on the research question: "*What conditions and activities have influenced the development of a competence-based curriculum for the Faculty of Education at UEM?*" Actors and factors influencing the development process were identified, such as the availability of resources (finance, physical infrastructure; support from management; the ideas of Dutch partner universities, etc.

### **The curriculum in operation, the implementation phase**

The implementation of a competence-based curriculum for the Faculty of Education of the UEM was reconstructed and analysed focusing on the common core part of the three post-graduate programmes.

Again three points of view in the analysis involved the characteristics of the implemented curriculum (substantive focus), the technical-professional aspects of the implementation process and socio-political aspects that influenced the implementation.

The analysis through the substantive lens was carried out based on ten curriculum aspects (Van den Akker, 2003) The aspect of generic competencies was added. The results of the analysis were used by the researcher to complete a checklist about competence-based characteristics of the implemented curriculum that was made based on the literature review and contained 20 items. In the end a "profile" of the implemented curriculum was obtained.

Students were in general positive about content and learning environments and accepted the assessment as it came, without much criticism. In their self-assessment of generic competencies a development of all competencies was perceived, with a strong development in ICT competencies. They showed a good understanding of the concepts of competence and competence-based education.

From a technical-professional point of view it was observed that the prevailing communicative approach, involving all staff, was continued by the Dutch side, but less prominently by the Mozambican staff, because they got increasingly involved in their own courses. This might be one of the reasons why proposals for a revised common core in the next 'edition' of the programmes did not 'land' with all staff, and were not seen by the leadership of the faculty as opportunities for staff reflection and development. This happened despite reports, made by the researcher based on observations, interviews and questionnaires, that served the formative evaluation during the implementation of the common core.

From a socio-political point of view it was noted that the implementation of the curriculum took place under the formal leadership of one person, the Dean who, perhaps because of his unique (formal) leadership status, did not delegate much to other staff. The overall coordinator of the Masters programmes functioned as a Deputy-dean, but without formal status, which may have contributed to the failure of a number of initiatives in the area of formative evaluation of the curriculum implementation.

## **6. Yield of the study**

The main aim of the study was to design and implement a curriculum for a new faculty of Education at UEM, consisting (mainly) of three masters programmes. An additional purpose of the study was to get an understanding of the extent to which competence-based education could be realised in a developing country like Mozambique and to describe and analyse the factors that influenced the design, development and implementation process. Use could be made of the state-of-the-art knowledge about learning, development of competencies and the 'engineering' of learning environments for such learning and development.

Inherent to an educational design research approach is that the conclusions of this study should include lessons or recommendations for universities and other institutions for Higher Education in Mozambique, and in other developing countries that would wish to develop their curricula in a similar direction. Design criteria for a competence-based curriculum and the procedural guidelines for design, development and implementation of such a curriculum were formulated as a result of the reconstruction, analysis and reflection of the curriculum development process. Design criteria for a competence-based curriculum and the procedural guidelines for design, development and implementation of such a curriculum were formulated as a result of the reconstruction, analysis and reflection of the curriculum development process. Some of them have already been mentioned above. Some important guidelines are:

- It is important to involve all staff in the design and development process and create during the process opportunities for learning and development.

- It is important to set up a functional communication network, linking all the actors involved in the curriculum development process.
- In a curriculum development process where staff members are co-designers and developers, the (curriculum) leadership should manage this process by providing clear directions and support at the same time.
- Special implementation issues could best be addressed by forming working groups. These groups should have an official status and their activities should regularly appear on the agenda of leadership meetings.
- Implementation of an innovative curriculum should be done through an implementation plan that should have the following characteristics:
  - Be a flexible 'script' of implementation steps.
  - Include instruments for formative evaluation and monitoring.
  - Contain a staff development plan.
  - Outline a clear and easily accessible support structure.

Recommendations were made as well with respect to the further development and implementation of a competence-based curriculum for the Faculty of Education at UEM and to further research.

## 7. Reflections

The study concerned the reconstruction, analysis and reflection applied to the design, development and implementation of a competence-based curriculum for the Faculty of Education of UEM. Embedded in the reconstruction and analysis are small (formative) design studies that were done at various moments during the curriculum development process, aimed at "optimization of the quality of the intervention as well as testing design principles" (Van den Akker, 1999, p.6). While formative research activities during the curriculum development process were aimed at optimising product and process, the reconstruction and analysis can be seen as an evaluation of the quality of the product, that is, the curriculum in its various representations, and an analysis of the curriculum development process. This analysis has been done through a technical-professional lens, emphasising the procedural aspects and a socio-political lens, focussing on 'actors and factors'.

The evaluation of product and process through an intervention model, inspired by Rossi and Freeman (1993) and Rossi, Freeman and Lipsey (1999) represented a mental exercise aimed at formulating various hypotheses (see above).

The mental exercise resulted in a list of indicators for the assessment of the competence-based characteristics of a curriculum, and a number of procedural guidelines (see section 5 of this paper) that follow from the analysis of the reconstructed curriculum development process.

### **Reflection on the researcher as designer and as member of staff**

As outlined above, in section 2, the researcher assumed as well the role of a designer started his research. After the formal curriculum stage the designer role diminished and the role as researcher/observer became more important, because staff was now fully responsible for the operationalisation of the formal curriculum. At the same time his influence as 'leader' in curriculum issues (some staff gave him the nickname 'general of the generic competencies') had diminished considerably because the Installation Committee had de facto been dissolved while the curriculum leadership had effectively not been taken over. So, the designer-researcher started as team member, became a designer and later on more and more observer.

Odenthal (2003) mentions the advantage of being a "dedicated participant" in getting, through a more intensive contact, more and deeper insights in the phenomena under study. There is, on the other hand, the difficulty of being able to keep the distance, needed for an unbiased view.

During the research described in this study the researcher had an outspoken role as dedicated participant throughout the curriculum development process. It is described by Lincoln and Denzin (1998) as one of the possibilities to "speak authentically about the experience of the Other" (p.411). By carefully documenting and reporting the different perspectives the study has stayed close to this process and offers readers the opportunity to build their own interpretation for use in his own context (cf. Van den Akker, 1999, p. 12).

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## Value of Delphi Technique as an Educational Design Research Method: Building a Model for the Design of Chemistry Laboratory Experiments for Instruction

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# 49. Value of Delphi technique as an educational design research method: Building a model for the design of chemistry laboratory experiments for instruction

Tara Bunag & Wilhelmina Savenye

## Abstract

*This case study describes the use of the Delphi method in conducting an educational design research study involving the building of a university undergraduate chemistry teaching laboratory design model. The study was conducted in a series of phases. These began with a preliminary phase (stage 0), an extensive literature review, which yielded the first round of survey questions. This was followed by a design/development phase (stages 1-5), and an assessment, or verification, phase (stage 6). Fifteen chemistry laboratory experts, who had published chemistry laboratories in a leading chemistry education journal, participated in the study. Twelve of the experts completed a series of in-depth Delphi surveys. They initially identified factors critical to designing chemistry laboratory experiments for teaching students chemistry, then later determined the importance and timing of these factors. The experts then responded to a prototype version of a model for building laboratories. Finally, this model was subjected to a review by three additional experts, who verified the accuracy and utility of the model. The study's findings indicated that Delphi can be an effective methodology for conducting educational research studies, and yielded a model for designing chemistry laboratory experiments for instruction. Additionally, the methodology can be adapted to designing laboratories in other scientific fields.*

## 1. Introduction to the problem

### The problem of chemistry laboratory design

This case study describes the use of the Delphi method in conducting an educational design research study involving the building of an undergraduate chemistry teaching laboratory design model. While the purpose of this chapter is to describe the processes involved in the development of the model, the basics for the model developed will also be briefly presented. Chemistry laboratory research has been complicated by the lack of a design model to guide the best practices in creating novel laboratories. Research into the efficacy of the chemistry laboratory does not fully support its benefits in aiding student learning, yet the laboratory is heralded as an essential aspect of learning chemistry (Brooks, 1970; Carmody, 1935; Hawkes, 2004; Lippincott, 1969). One challenge of evaluating the efficacy of the laboratory is the lack of a common design structure for developing chemistry laboratory experiments for teaching, and a lack of training of individuals designing such chemistry laboratories. For instance, in this study we found that none of the 15 chemistry laboratory design experts involved had received formal training in designing chemistry laboratories.

The purpose of the educational design research study was to employ the Delphi method to: first depict the current practices of chemistry laboratory design experts, and secondly to develop a

research-based instructional systems design model for chemistry teaching laboratories. Then, the model was evaluated to determine the degree to which the experts thought it was an accurate and useful model of current practice. Richey and Klein (2009) suggest that the Delphi method can be used for model development.

The study investigated three basic research questions, involving:

1. The variables chemistry laboratory design experts consider when they plan new labs.
2. The priorities and sequence these experts consider when applying these variables.
3. In the eyes of these experts, how these variables contribute to a model of chemistry laboratory design.

The Delphi method involves gathering information from experts in a particular field to determine the answer to a particular research question (Skulmoski, Hartman, & Krahn, 2007). This method can be used to gather information from experts for a number of possible purposes, including model development. Information is gathered in a series of iterative questionnaires, allowing experts to review and reflect on responses from all participants and refine their ideas in each subsequent round of questionnaires. Results are often validated by incorporating additional research methods, such as interviews or additional surveys (Skulmoski et. al, 2007).

The Delphi method first requires the identification and recruiting of experts within the field (Skulmoski et. al, 2007). Participants were identified based on publications in the Journal of Chemical Education and by nomination from individuals who published within the Journal of Chemical Education. Experts had published at least twice on undergraduate chemistry laboratories, or they were recommended by individuals who had at least two publications, thus meeting this criterion. Sixteen experts were identified, with thirteen identified for the Delphi portion of the study and three identified for verification.

The study was conducted in a series of phases, with one or more stages in each phase. These included a preliminary phase (stage 0), design/development phase (stages 1-5), and an assessment phase (stage 6). These stages are depicted in Figure 1). Stage 0 involved literature review and determining the best approach for performing design and development of the model. Stages 1 through 5 involved three rounds of Delphi surveys, informed by literature review to develop the model. Finally, stage 6 involved verification interviews to evaluate the model. These stages are further described throughout this chapter.

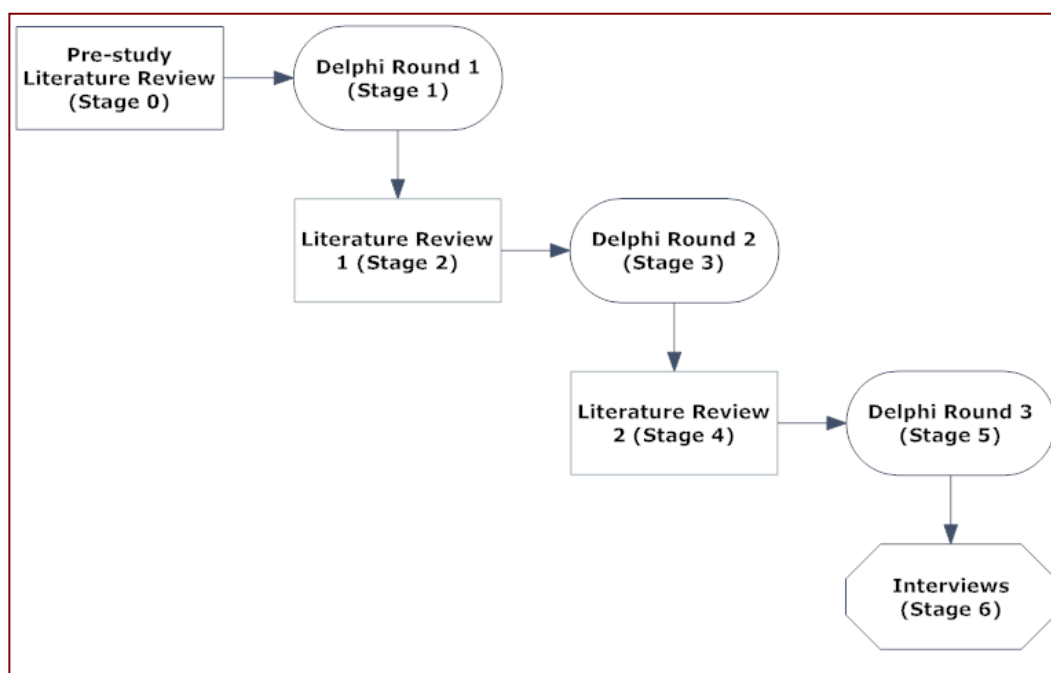


Figure 1: Stages of the study. This figure depicts each stage of the study and the sequence of the stages. (Bunag, 2012; reprinted with permission)

## 2. Preliminary phase: Stage 0

The study began with a review of existing literature on the design of chemistry laboratories. Following this review, the Delphi method was selected as an appropriate methodology, and, based on the review, questions for the first round of the Delphi study were developed.

### Existing design models

First, it was necessary to determine if there are any existing instructional systems design (ISD) models commonly used in undergraduate chemistry laboratory design. In an extensive review of the literature, no ISD models were found that are commonly used in the field, however, the 5E model is a five phased cyclic lesson design model that has been used for chemistry laboratory design (Ansberry & Morgan, 2005). The five phases of the model are “Engage, Explore, Explain, Elaborate, and Evaluate” (Ansberry & Morgan, 2005, p. 27), and these phases describe how the students interact with the content of the laboratory. The 5E model is most commonly applied at the secondary education level, and is not commonly applied within the undergraduate chemistry literature. The 5E model is a learning cycle, not a development process, but it does highlight the cyclic nature of instruction in the sciences.

### Determining an appropriate methodology

The purpose of this educational design research study was to build a model based on a depiction of experts’ real and current practices, which is best accomplished by gathering data from existing experts within the field. An educational design approach was deemed to be most suitable for the study, as it involved, as Kelly (2006) described, an area in which the problem was “substantial” (p. 75), and, as noted earlier, there are few to no guidelines to support instructors who develop chemistry laboratory experiments for learning. The instructional problem is thus “open” and considerable (Kelly, 2006, p. 5).

Chemistry laboratory design experts are busy individuals, and the design process does not occur at one specific time of the year. This suggested that the method chosen needed to be simple to complete, non-invasive, and retrospective. A retrospective approach is not ideal, so the method chosen would also require additional verification. An appropriate methodology for this purpose is the Delphi method, since it allows for gathering data from experts through a series of surveys, with systematic opportunities for the experts to reflect on data summaries and the model, with the goal of determining a consensus (Skulmoski et al., 2007). One challenge with the Delphi method is determining the questions and the depth of the questions for the first round of the Delphi surveys (Skulmoski et al., 2007).

### **Creating questions for the first round of the Delphi surveys**

The first round of Delphi surveys can start with narrow or broad questions, depending on the purpose of the study (Skulmoski et al., 2007). Because the review of the literature indicated that there is no existing model of chemistry laboratory design currently used for developing undergraduate laboratories, the first round survey would need to be broad. This would allow the collection of the most information possible on the process of laboratory design. Although there is no existing model, there have been a number of studies focussed on specific design choices, as further described below. These studies provided a framework for developing the first-round questions.

The intent of the first round of the Delphi survey was to determine the variables of instruction that are relevant to undergraduate chemistry laboratory design. Variables of instruction in this context are defined as the items, along with their possible parameters, that experts would make decisions about while designing a laboratory. The literature in chemistry laboratory design indicated a number of categories of variables that may be important throughout the design process. For example, for many chemistry lab instructors, variables related to the content of the lesson are important (American Chemical Society, 2008; Cacciatore & Sevian, 2009; Reingold, 2001). Choices lab instructors and designers must make, for example, might include how to decide what content to build into the lab, on what student outcomes to focus, and how the lab content will fit into the course sequence.

Many other decisions and choices are made by laboratory designers and instructors. Assessment decisions, including what learning to assess, and how, are also particularly relevant to lab designers (Towns, 2010). Physical considerations may include facilities, logistics and cost (Beckrich, 2010; Moretti, 1997; Corkern, 1991; Smucker & Weaver, 1959). Decisions must also be made about the characteristics of the student population (American Chemical Society, 2008; Reingold, 2001; Szalay, Zook-Gerdau, & Schurter, 2011) and the type or style of lab to be developed (Cacciatore & Sevian, 2009; Domin, 1999; Lagowski, 1998). What teaching materials to employ is also of concern (Cacciatore, 2010; Cacciatore & Sevian, 2009; Özdilek & Özkan, 2009). Finally, choices are made regarding the experimental conditions of the laboratories (Dean, Miller, & Brückner, 2011; Lang, Miller, & Nowak, 2006; Noey, Curtis, Tam, Pham, & Jones, 2011). Questions for the first round of the Delphi study were constructed based on these categories and the types of considerations noted within the literature review.

The first round of the Delphi survey had the second purpose of verifying the expert status and homogeneity of the survey participants. The expert status is necessary for creating a model that is based on the current practice in the field. Evaluating the homogeneity is necessary to determine if an appropriate sample size was used for the Delphi survey, since a homogeneous population requires a smaller sample size than a more diverse population (Skulmoski et al.,



2007). Current literature on diversity within chemistry suggested that the population was relatively homogeneous in terms of both demographic information and beliefs concerning the chemistry curriculum (Harris & Woods, 2009; Melton, Parr, Caldwell, & Sherry, 1977; Neuschatz, Ryan, Wesemann, & Boese, 2003), but this needed to be verified within the sample. This required the addition of demographic questions to gather this information. Demographic questions included gathering information on the experts' completed degrees, institutional affiliation, prior teaching experience, experience developing laboratories, training on developing laboratories, and beliefs regarding how students learn best in the laboratory at different chemistry levels.

### **3. Design and development phase: Stages 1-5**

#### **Purpose of the design and development phase**

The purpose of the design and development phase was to gather information from the chemistry laboratory design experts and refine that information through additional expert review and review of the literature to create the instructional systems design model. This involved an iterative process of refining the ideas of experts to reach a consensus. Each stage within this phase was built on the previous stage.

#### **Stage 1 - Delphi round 1**

Questions developed during stage 0 of the study were used to create an electronic survey for participants to complete. Thirteen participants were recruited to take part in all of the surveys, and they were sent individualized invitations to complete the survey. Seven questions in this stage of the study were multiple-choice, while 27 were open-response questions, to allow for collection of the most information regarding current practice and beliefs concerning chemistry laboratories at the undergraduate level. This was a relatively long survey, though previous research using the Delphi with this population suggested that chemistry participants would be willing to complete a long survey (Melton et. al, 1977). Twelve of the thirteen participants responded to the survey.

#### **Stage 2 - Literature review 1 and data analysis**

Data from the first round of the Delphi survey were organized and categorized with the intent of retaining as much information as possible. Variables within each participant response were identified, and the number of times a particular variable appeared within different participants' responses was tracked. Certain variables appeared as responses to multiple questions, and these were combined to create a list of the variable themes identified in one or more responses. At this stage, all variables themes were retained, even if they were only mentioned in one response. Literature review was used to verify if the variable themes that were only mentioned once were important within the field. The two variable themes of noise and ethics were the only items mentioned just once, and the importance of these variables was highlighted within the literature (Butcher, Mayo, Pike, Foote, Hotham, & Page, 1985; Gillette, 1991; Kandel, 1994; Kovac, 1996; Lewis, 1947; Saunders, 1987). This resulted in the identification of 47 variable themes. Themes mentioned by close to half or more of the experts included, for example, developing labs based on lecture content (mentioned by 6 of the experts); sequencing (9) and determining outcomes (5) of the lab also based on lectures; assessing students in lab via written reports (9) or exams (7) among other methods; and assessing success of the lab based on good lab results (5). Safety aspects also yielded variable themes, such as general safety concerns (6), avoiding toxic chemicals (8), and applying green or household chemistry (5). Other frequently mentioned themes included keeping labs to one session (8); concerns

regarding costs (6) and equipment (5); results of previous experience (5); use of lab manuals (10), instructor supplements (8) and information (8), and expository (6) or guided inquiry methods (5). Experts also mentioned organizing labs to fit a course (7), testing it with students (5) and that they typically supervise the labs (7).

These variable themes were then used to create 47 question stems for the second round of the Delphi survey. For example, laboratory and technological skills were mentioned by a number of experts for multiple questions. This resulted in the variable theme of "Emphasizing appropriate laboratory skills (industry, research, grad school, etc.) including technological skills" which was turned into the question stem "Emphasizing appropriate laboratory and technological skills based on skills needed for industry, research, or graduate school" (Bunag, 2012, p. 52).

### **Stage 3 - Delphi round 2**

Questions developed during stage 2 of the study were used to create an electronic survey using Likert-type items. Each question stem developed in stage 2 was used twice. First, participants were asked to rate the importance of the variable theme by selecting one of the following options: "very important, important, neither important nor unimportant, unimportant, very unimportant, or not applicable". Second, participants were asked to select the order in which the item was considered in designing chemistry laboratories, with the options of selecting one or more of the following options: "before I start designing the lab, at the start of the design process, in the middle of the design process, near the end of the design process, right before the first time the lab is conducted, after the first time the lab is conducted, and not applicable" (Bunag, 2012, p. 56). Finally, participants were asked an open-response question to allow for feedback on any items that should have been included in the survey but were not. This type of question is important within studies using the Delphi method to allow experts to reflect on and provide feedback on their prior responses.

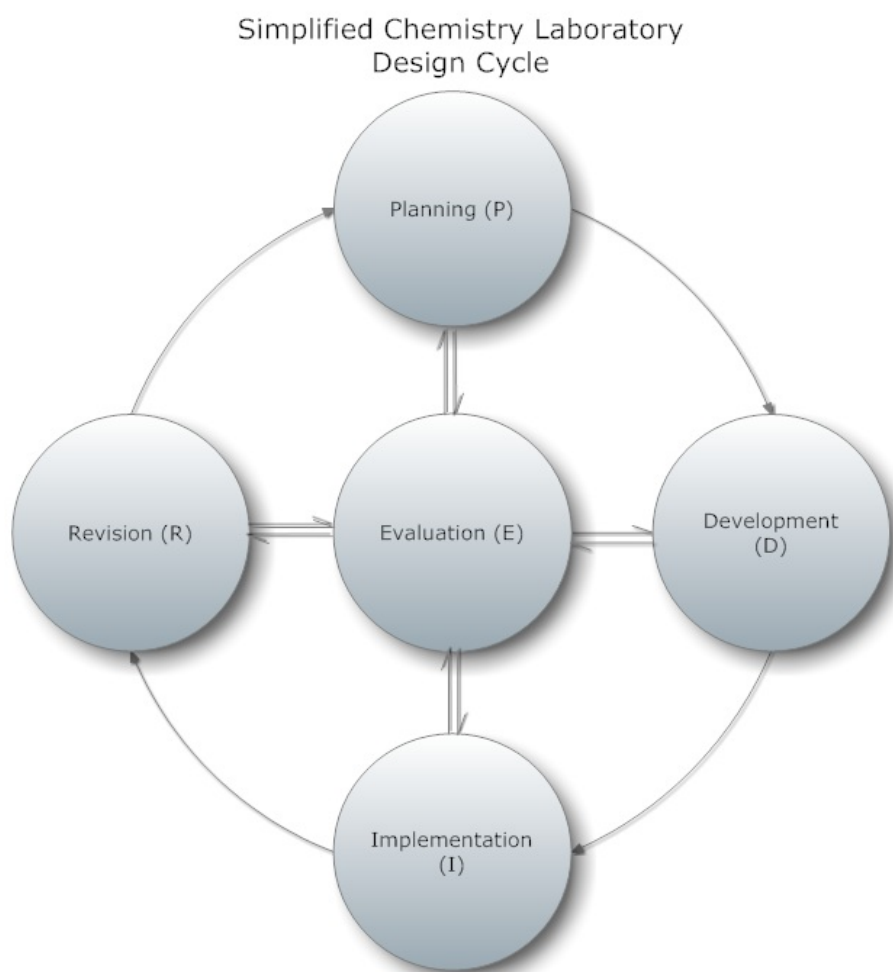
### **Stage 4 - Literature review 2, data analysis, and model development**

This stage was intended to clarify the responses from the second round of the Delphi and determine if it would be possible to develop a model from these results. Based on the data gathered, it was possible to construct a model.

Responses to the second round of the Delphi survey first were used to determine the relative importance of the variable themes. Since the variable themes were based on the participants' responses, it was expected that experts would find them important, and this was verified in the analysis of the data. Only one variable had a low importance rating, and this variable was noise, as supported by it being mentioned just once in the first round of the Delphi survey.

The responses to the second round of the Delphi survey also allowed for determining the order in which variable themes are considered during the undergraduate chemistry laboratory design process, and this, combined with data from the first round and the literature, allowed for development of a preliminary model of the design process. A few patterns emerged from analysis of these data. First, there were certain variable themes that were only considered at one or two times during the development process. This allowed for ordering these items within a relative development timeline. Second, the experts indicated they considered some variable themes, such as student interests and skills, throughout the design process. Open-response feedback from both rounds 1 and 2 of the Delphi surveys suggested that the design process was cyclic, not linear. This allowed the development of a model that exemplified the cyclic nature of laboratory development and the items considered throughout the process.

The variable themes that were considered only at specific times in the process fit into groups that suggested specific phases within the development cycle, as seen in Figure 2. First, variable themes that were early in the process were best described as elements of planning, including both analysis of the existing resources and some preliminary design considerations. Second, variable themes later in the design process fit together as a development phase, including some additional design decisions, but mainly characterized by the development of the materials, experiments, and processes necessary to conduct the laboratory. Third, implementation of the laboratory occurs, along with collection of data and adaptation to allow the laboratory to run successfully. Finally, the laboratory is revised based on the data collected, and the information cycles back to planning. Throughout all of these phases, there is a constant phase of evaluation that requires reflecting on the inclusion of certain variable themes that are important for all parts of the process.



*Figure 2: Simplified undergraduate chemistry laboratory design model (Bunag, 2012; reprinted with permission)*

We found it particularly interesting that this model for chemistry laboratory design, derived from experts who were not particularly knowledgeable about instructional design, so closely resembled traditional instructional design models. The derived model was a procedural model, per Richey, Klein, and Tracey (2011), in that it was based on these experts' experiences. The

phases of the derived model are similar to the phases in the ADDIE model (Molenda, 2003), but it is the content within each phase that distinguishes this model. The model includes specific considerations that are unique to chemistry. For example, the Evaluation phase of the model includes the considerations listed in Figure 3.

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E. Evaluation (Continuous process)

- a) Consider the balance between each phase of the cycle (P, D, I, or R) and each of the following:
- > Safety for the student or the environment – How can safety be ensured? How can the lab teach safety skills?
  - > Student interest or motivation – What motivates students? How can motivation be increased?
  - > Match to student skills – What skills do students have already? What do they need? How do these relate to their laboratory skills?
  - > Student problem solving skills – What skills do they possess? How can problem-solving skills be developed?
  - > Ethics of conducting experiments – Is the lab ethical to conduct? How can the lab reinforce experimental ethics?
  - > Other instructors who may teach the lab – What feedback can other faculty provide? What details need to be provided for the individuals (faculty, TA's, etc.) who may teach the lab?
  - > Match to goals – Does the laboratory match the intended goals? How will it improve the quantity and quality of student learning?
- 

Figure 3: Considerations within the evaluation phase of the model (Bunag, 2012; reprinted with permission)

Development of this model involved using the information provided by the experts and informed by the literature. One of the challenges of developing a model of current practice within the field is that current practice may not fully align with accepted best practices within instructional design. When this occurs, a decision must be made regarding the model. Will the model adhere more closely to current practice or to best practices? In this study, the purpose was to develop a model that depicts the current practice. As such, the model includes some elements that are somewhat in conflict with best practices or demonstrate areas in which the literature shows some disagreement on best practices. For example, there is some uncertainty in the model concerning when the development of assessments takes place, and this mirrors disagreement in the literature concerning whether assessment should be developed early (see Dick, Carey, & Carey, 2011; Gagné, Wager, Golas, & Keller, 2005; Smith & Ragan, 2004; Wiggins & McTighe, 2006) or late in the design process (see Gagné et. al, 2005; Sullivan & Higgins, 1983), though some of this disagreement is based on the different purposes of assessment as a method of evaluating the achievement of discrete objectives (such as can a student perform a titration?) versus the use of assessment in comparing individual learner's achievements (such as who can perform a titration most accurately?).

Once the preliminary model was developed, this allowed the development of the questions for the third and final round of Delphi surveys. The purpose of the final round of surveys was to determine the accuracy, usability, and practicality of the preliminary model and to gather data concerning the changes that needed to be made to improve the model.

### **Stage 5 - Delphi round 3**

Questions for the third round of the Delphi surveys included both Likert-type questions and open-response questions. The Likert-type questions were written as statements, and the participants were instructed to select how much they agreed with the statement, with the options of “strongly agree, agree, neutral, disagree, strongly disagree, or not applicable”. Likert-type questions included, “This model describes what I do when I create a new chemistry laboratory experiment,” and, “I plan on using this model when I develop new chemistry laboratory experiments,” (Bunag, 2012, p. 73) in addition to more specific questions concerning the organization, phases, steps, and usefulness of the model. The open response questions allowed for elaboration on the Likert-type responses, such as with the question, “How would you use this model?” (Bunag, 2012, p. 79), which allows the participants to clarify their response to “I plan on using this model when I develop new chemistry laboratory experiments” (p.73).

These statements were supported with open-response questions to allow for clarification of the responses. Participants were asked to provide their feedback on items such as how to improve the model, how useful they felt the model would be for development of new experiments by experts or novices, how the model could be taught, how they might use the model, and any other changes they would suggest. In developing these questions, the open question regarding changes was important, to allow for improvements that may not fit into other categories. Also, a question was included to allow for more general comments, so that participants could express their other ideas concerning the model.

Data from these questions was used to refine the preliminary model to create a revised model. Most of the feedback on the model was very positive, suggesting few changes needed to be made. The suggestions for the model involved minor revisions that were applied to develop the revised model. This process required first determining what a minor or major revision would be within the model and what the thresholds would be for making these changes.

In this model, a minor revision involved re-ordering of considerations within a phase or the addition of clarifying steps. For example, some participants suggested that the order of certain items, such as considering the lecture material, were in the wrong order in the planning phase. Re-ordering of the considerations was determined to be a minor revision because the order in each phase could not be determined from the data from the previous rounds of Delphi surveys. Considerations were placed within a phase, but no further order was intended by the preliminary model. These minor revisions add meaning to the order of the considerations in each phase. These minor revisions were made, even if just one individual suggested them, since they did not remove or add any phases or other parts of the model and none of the suggestions conflicted. Major revisions for this model would include moving, removing, or changing a phase or adding other components to the model. Only one major revision was made to this model. This involved adding instructions on the intent of the model, the organization of the model, and a caveat to consider additional unique considerations, which was suggested by multiple participants. Major revisions were only made if three or more participants suggested the change, since there was generally high agreement on the accuracy of the preliminary model.

## **4. Assessment phase: Stage 6**

### **Stage 6 - Interviews**

The revised model was sent to three additional undergraduate chemistry laboratory design experts who were selected using the same criteria as the survey participants. These three experts did not participate in the previous surveys, but they were asked to participate in

interviews to evaluate the validity of the revised model; they were given one week to review the model.

The interview participants were asked the same demographic questions as were the survey participants to ensure consistency between the participant groups. They were then asked four questions concerning the revised model, specifically regarding their general impressions of the model, the usability of the model, suggestions on how to improve the model, and whether they would consider using the model.

The interview participants all provided responses indicating that the revised model was accurate, and they agreed that they would find the model useful. The participants provided a few additional minor revisions to the model, but overall, this evaluation supported the validity of the model. For example, one of the participants suggested listing safety first in the evaluation phase, and this re-ordering is reflected in Figure 3.

## 5. Yield of the study

### The final model

The intent of this case study is to describe how the model was developed, versus describing the final model itself. Models developed using the Delphi method may be very different from the one developed in this study, depending on the field where the method is applied. With this context in mind, the model is described below.

This study resulted in the development of an instructional systems design model of how expert undergraduate chemistry laboratory designers develop new experiments for teaching. The experts found the model to be accurate, appropriate, and useful, particularly in highlighting design considerations that were not considered consciously. This allowed the experts to consider the importance of these considerations and how they might contribute to an improved laboratory design. Though this model was validated to be accurate by expert chemistry laboratory designers, it may not represent the best practice within the field and it may not represent the process required by novice designers. These are possible limitations of the study. The efficacy of the model would need to be evaluated to determine if it also illustrates the best practice for the field, and the usability with novices would need to be evaluated in order to ensure it can be used by this population to design chemistry laboratory experiments for their teaching.

The model includes five phases, with specific steps that are considered within each phase, as shown for evaluation in Figure 3. Four of the phases in the model form a cyclic process, while the fifth “phase”, evaluation, is a continuous process, considered at all points in the design process. A simplified version of the model showing the phases is depicted in Figure 2.

### Professional development

In addition to verifying the accuracy of the model, these experts noted that the model provided them with a new perspective about the considerations involved in designing chemistry laboratories. Participants noted that certain considerations are important to design, but that they did not typically consider these considerations directly. This was most easily observed during the interviews. One participant was initially uncertain of how ethics applied to the chemistry laboratory design process. Later in the interview, the participant told a story to demonstrate how the model relates to the design process. In the middle of the story, the participant realized that the key consideration involved in this particular story was ethics. This highlights the potential of both the model development process and the final model development in contributing to professional development and awareness of previously hidden considerations of design.

Developing an awareness of these considerations can then allow laboratory designers to address these considerations in a meaningful manner.

### **Generalizability**

As in all model development, it is important to consider the generalizability of the model. However, in educational design research, as Plomp (2010) has argued, generalizability is not in the specific application of findings exactly to another context. It is rather related to what Yin (2003) calls analytical generalizability of case studies (2003). Generalizability in these studies is related instead to the goal of applying findings of a study to development of a broader theory. The model derived in this current study is limited to undergraduate chemistry laboratory design, but the inclusion of multiple individuals internationally may allow it to be applied in a wide geographic context. Although this model is only directly applicable to instruction for undergraduate chemistry, participants suggested that the model may be applicable to other contexts. Participants specifically suggested that these could include other levels of chemistry education, such as the secondary level, or to other fields of science, such as biology or physics. Some of the participants also design instructional materials for other levels or fields, but the model was not evaluated for application in these areas.

### **Value of the method**

The Delphi method met the needs of this study, demonstrating its utility in addressing questions in educational design research. This study also demonstrates the feasibility of constructing theory based on current practice. Participants suggested that this method could be used further to study practice in related fields, but it may also be useful in studying design in any well-defined field.

## **6. Reflection**

### **Potential directions for further educational design research**

There are a number of directions for the next step in research involving the model developed in this study. These further studies could address the possible limitations of this study, including determining if this is an effective model for designing experiments for science instruction, and the degree to which the model can be used easily by individuals at varying levels of experience. This could include evaluating the model to determine if it could be used in other levels or fields, evaluating the usability of the model by experts or novices, or evaluating the efficacy of the model in addressing a specific educational goal. The Delphi method could be used to evaluate the accuracy of the model for other levels or fields, but other methods would be needed to address the other research purposes. Usability and efficacy could potentially be evaluated concurrently through the development of new experiments without and with the model. Studying usability or efficacy would require methods other than the Delphi method. Such methods would include, for instance, more qualitative methods, such as interviews, observations, and student artefact analysis, as well as surveys.

This model may also build a foundation for determining best practices within undergraduate chemistry laboratory design. Ideally, this would provide an additional tool to improved learning outcomes and a clear determination of the role of chemistry laboratories in student learning.

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## Designing a Conducive Learning Climate for Self-organized Learning in Sensire's Home Care Teams

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# 50. Designing a conducive learning climate for self-organized learning in Sensire's home care teams

Tim Hirschler, Frank Hulsbos, Stefan van Langevelde & Frank Hulsbos

## Abstract

This article describes a design-based research in the Dutch home care organization Sensire. The study aimed at improving Sensire's home care professionals' ability to self-organize their learning. In order to address the problem we conducted a study that consisted of a practice stream and a knowledge stream. In the practice stream we designed an intervention that supported a specific home care team to create a climate for self-organized learning. The knowledge stream reflected on the practice stream in order to glean successful elements and design principles to support self-organized learning in similar home care teams of Sensire. We developed a conceptual framework to study self-organized learning by making use of social capital theory, self-determination theory and distributed team leadership and shaped the study based on the principles of appreciative inquiry. Our study has yielded practical and scientific knowledge. We describe practical knowledge in terms of breakthroughs and personal learning yields in the context of one specific home care team. The most important yield in terms of practical knowledge is that working from urgent work-related questions supports self-organized learning. An important breakthrough in the work environment is that both home care professionals and managers developed a stronger ability to self-organize learning, mainly because their relationship has improved. Additionally, we describe scientific knowledge in terms of generic knowledge about self-organized learning in Sensire and design principles in order to support it.

## 1. Introduction

In 2011 we conducted a study at Sensire, a large healthcare institution in the Netherlands. Sensire offers a broad range of healthcare services, ranging from house cleaning to maternity care to home care. Our study focused on the department of home care, which works on the basis of teams, consisting of team members with different degrees of subject matter expertise. The main objective of this study was to create a learning climate that supports teams of homecare professionals to self-organize their learning. Self-organized learning is characterized by a high degree of decision space for professionals to take initiative in identifying learning needs and taking steps towards achieving them (Knowles, 1975). Within Sensire earlier efforts were made to reduce team size and replace team managers by positioning care-related experts at the heart of these teams instead. However, demands for external accountability and rules and regulations were factors that inhibited the growth of such a learning climate. This created a tension and caused dilemmas for both professionals and management. In order to tackle this problem Sensire asked us to conduct a study on factors that promote and inhibit a learning climate for self-organized learning.

Based on the research problem we formulated the following research question:  
How can Sensire create a learning climate in which home care professionals self-organize their professional developmental process?

To address the research problem, we developed a conceptual framework based on social capital theory, distributed leadership, self-determination theory and appreciative inquiry. Social capital refers to the quality of relationships that support learning within an organization (De Jong, 2010). Distributed leadership emphasizes that not only formally assigned leaders deploy leadership activities, but many (and in theory all) organizational members do, depending on a specific situation (Spillane, 2006). Self-determination theory describes what psychological needs are important for professionals in order to support intrinsic motivation to learn and develop (Deci & Ryan, 2008). Appreciative inquiry represents a pragmatic approach with a focus on those organizational and individual factors that have been proven successful (Cooperrider & Whitney, 2005). The theories and subsequent detailed research questions are further explained in section 2.

The research problem is complex and involves many stakeholders, therefore no straightforward solution is available. Because of this we decided to apply design-based research, as this is a research design appropriate for problems for which no ready-made solution is available (Kelly, 2009).

Our study can be described as a consultancy trajectory in which we used scientific theories to guide design and reflect on the consultancy trajectory. For the design we used the Design-Based Research (DBR) model proposed by Andriessen (2007), which distinguishes between research activities in a 'knowledge stream' and a 'practice stream'. In the practice stream we experimented with new practices in a specific home care team aiming for an optimal intervention, i.e. an approach for self-organized professional development. The practice stream consisted of three consecutive stages with a team of home care professionals. This stream has practical outcomes, which can be described in two ways: yields in the work context and personal learning of stakeholders that occurred during the research. The knowledge stream consists of reflective activities, in which we looked at the research process to glean the successful elements in supporting a learning climate for self-organization at Sensire. In this stream we developed generic knowledge with the aim to better understand how social capital theory, self-determination theory and distributed leadership manifest themselves in practice and how they can be supportive of a learning climate for self-organization. Based on these insights, we formulated design principles to support self-organization at Sensire.

With this chapter we hope to give insight in how design-based research can be used in a consultancy trajectory in the context of organizational learning. This chapter is structured as follows. Section 2 describes in detail the context of Sensire and our theoretical building blocks. In section 3 we describe the stages and formative evaluation activities of our study. Section 4 summarizes the yields of our study in terms of generic knowledge, breakthroughs in the work environment and personal learning. In our final section we discuss lessons learned.

## **2. Development of the conceptual framework**

To address the research question we first explored the context of the question in our initial contact with the management team and by examining Sensire's policy documents and statements. This activity is part of the practice stream. From there, we determined in the



knowledge stream which contemporary scientific theories seemed best suited to the question at hand.

The next sub-sections describe our context analysis and the scientific theories we selected. Together these elements embody the conceptual framework (see Figure 1). We end this section by formulating our detailed research questions.

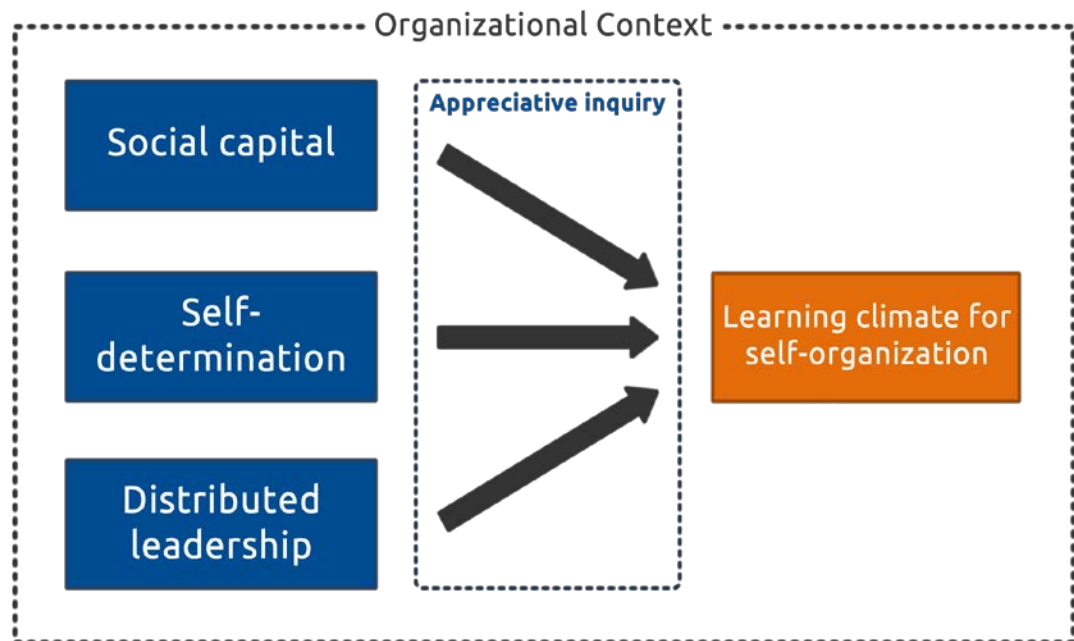


Figure 1: The conceptual framework

### The organizational context

Before drawing up the conceptual framework, it is important to understand the organizational context more deeply. To do so, we elaborate on one specific external challenge that characterizes Sensire's situation. The Dutch government has started pushing to reorganize health care on a free-market basis instead of a publicly funded basis. To control costs in times of an ageing population, the government simultaneously announced cutbacks in the home care budget. Healthcare institutions are thus more dependent on their financiers (e.g. insurance companies). This has led to an increased pressure for external accountability on prescribed performance indicators for health care institutions, such as having to register by the exact minute how much time a professional spends on certain actions and on 'team time'. These data are used to compare a patient's 'need for care' in minutes to the actual time spent delivering care, where any activity outside of the budget is not compensated by insurance. These external pressures were at odds with the need for home care professionals to take the customer as starting point for service. Within Sensire a wish emerged to find a solution for this conflicting situation. Therefore upper management took the decision to renew Sensire towards an organization that worked from a customer perspective, based on maximal self-organization and team-oriented working by the professionals. This is a promising direction, because home care professionals confront complex and unpredictable situations with customers daily. In order to operate at a high level in these situations, professional space to take decisions and cooperation with colleagues is essential. This way of organizing clearly accentuates the role of the individual

employee. It means that the professionals will become increasingly responsible for their own actions, the decisions they take, and to acquire the necessary competencies and skills that enable them to do so.

When we started our research, Sensire's home care department had already undergone several (mostly structural) renewals, in line with the organization's wish for increased self-organization. The size of a home care team was reduced from 30 to a maximum of fifteen professionals. Previously, each team covered home care for large areas of the village or city; in the new situation a team is responsible for a more specific geographic area ("neighborhood"). In addition, the teams' operational management layer was removed, while a care related expert was positioned in each team as a 'captain of care'. All of the 130 home care teams were assigned to a team coach, whose role is to support the teams in their development (see also section 3, exploring the client agenda).

### **Scientific theories**

Based on our context analysis and the general research question, we chose four scientific theories that we expected to be important in creating a learning climate for self-organization: social capital theory, self-determination theory, distributed leadership and appreciative inquiry. The following four sub-sections summarize these theories.

#### ***Social capital theory***

When developing mastery in their work, home care professionals utilize the support of their team and the organization where needed. Sensire also underlines this in their policy by noting that the organization's social capital is becoming more important and that professionals who are experts at a certain theme can support others in this area. De Jong (2010) states that social connections have a value because they enable people to learn, create networks and promote trust and reciprocity. The value of these relationships is called *social capital*. In this section we describe the *structural dimension* of social capital, which refers to the pattern of relations between people (Nahapiet & Ghoshal, 1998). This structural dimension is an important concept in our research because connections with other people, both inside and outside the organization, provide access to resources. In other words "who you know" affects "what you know" (Nahapiet & Ghoshal, 1998).

Several authors have discerned between three types of relations between people: *Bonding*, *Bridging* and *Linking* relationships (Field, 2003).

- **Bonding** relationships are relationships between persons who largely have the same background, such as close colleagues (team members), friends and family. These relationships are very important within the team, but we expect that only bonding relations will not be enough to support self-organized learning.
- **Bridging** relationships are relationships between people with a comparable background, but somewhat more loose. These are relations between people with shared interests, or between members of different work teams. Bridging relationships are important pathways for knowledge and experience sharing.
- **Linking** relationships are those that connect people with different backgrounds, for example the relationship we as external researchers have with the managers and home care professionals. Also, relationships across organizations or even different sectors are linking relationships. We expect linking relations to be highly important to gain access to a large array of knowledge resources.

In our research at Sensire we investigated in what way these different relations support self-organized learning.

### **Self-Determination Theory**

Self-organized learning implicates that professional development arises from the personal learning needs of a professional. The self-determination theory (SDT) describes this as *intrinsic motivation*, which refers to the natural tendency to seek and accept challenges when we pursue personal interests and possibilities. Intrinsic motivation is associated with better learning, performance, and well-being (Deci & Ryan, 2008).

Within the SDT the support and stimulation of intrinsic motivation is connected to satisfying certain basic psychological needs, namely: autonomy, competence and relatedness. These needs are described as follows:

- The need for autonomy is the feeling that your activities are endorsed by yourself and therefore are self-determined.
- The need for competence is the feeling of personal effectiveness and that you can effectively bring about desired effects and outcomes.
- The need for relatedness is the feeling that you are close and connected to significant others and part of a collective.

In our research we studied how Sensire could support these needs in order to enable home care professionals to self-organize their learning.

### **Distributed leadership**

An important factor within Sensire is the changing role of leadership. It is likely that increased professional autonomy, the removal of the teams' operational management layer and reduced team size ask for more people to exercise leadership. We wanted to discover where sources of leadership could be found and in what way these sources contributed to professional development. To this end, the literature on distributed leadership (Spillane, 2006) looked promising, as well as team leadership literature (Morgeson, DeRue, & Karam, 2009) that fits into the distributed leadership perspective.

In contrast to traditional conceptions of leadership, in which a select group of people exercise all leadership tasks, a distributed leadership perspective creates space for many and in theory all organizational members to take influence (Spillane, 2006).

In order to help Sensire find different sources of leadership we chose the description of Morgeson, et al. (2009), who give a clear conceptualization of distributed leadership in teams. They consider leadership as (intended) influence, which is aimed at trying to fulfill a team's needs. These needs are called *leadership functions* (Morgeson, et al., 2009).

Morgeson, et al. (2009) describe that different organizational members can exercise influence on these leadership functions. Influence can come from sources internal or external to the team, which Morgeson, et al. (2009) call the *locus of leadership*. A second dimension is the *formality of leadership*, which concerns influence on teams' leadership functions from formally versus non-formally appointed persons or groups. These two dimensions can be combined to form a quadrant of leadership sources (Table 1). The different sources each have their strengths and weaknesses in exerting influence on specific team leadership functions. Our interest was to find out which sources of leadership could be identified and how each source contributed to leadership practice within Sensire.

Table 1: Team leadership sources, adapted from Morgeson, et al. (2009)

	<b>Formality of leadership</b>		
	<i>Formal</i>	<i>Informal</i>	
<b>Locus of leadership</b>	<i>Internal</i>	Team leader Project manager	Other team members
	<i>External</i>	Coach Management Sponsor	Mentors Other teams

### ***Appreciative inquiry***

Appreciative inquiry is a pragmatic approach with a strong focus on those organizational and individual factors that have been proven successful. It builds on the strength of relationships, as professional development is supported by interactions amongst people (Cooperrider & Whitney, 2005). The appreciative approach brings with it an attitude of curiosity and acceptance. Frequently, the appreciative enthusiast will aim to formulate research problems and other questions in a positive way (e.g. not 'Why are some customers leaving?', but 'why are most customers staying?'). When departing from appreciative inquiry, self-organized learning requires a participatory approach in which people are invited to take the lead in their own development process. We therefore started our investigation from 'urgent work-related questions'. Urgent work-related questions are questions that stem directly from the primary work process and there is high urgency for these questions to be solved. Urgency does not only refer to a rational urge, but also to a personal feeling that there is an urge (Verdonschot, 2009). This means that organizational members who are involved need to formulate their questions in such a way that they feel a strong motivation to work on them. We expected these urgent work-related questions to be an important drive for self-organized learning.

### **Specific research questions**

On the basis of this conceptual framework we formulated the following detailed research questions:

1. What kind of bridging, bonding and linking relations can be identified in Sensire and in what way do they support home care professionals to self-organize their learning?
2. How do needs for autonomy, competence and relatedness express themselves in the work of Sensire's home care professionals and how can they be fulfilled?
3. Which sources of leadership can be discovered in and around the team of home care professionals and how do these sources of leadership interact with the different leadership functions in order to support a climate for self-organized learning?
4. In what way can an appreciative approach to organizing support self-organized learning at Sensire?
5. In what way does an urgent work-related question support home care professionals to self-organize their learning at Sensire?

In the next section of this chapter we will describe the research activities we conducted in order to answer our research questions.

## **3. Design and development**

In describing the various phases and activities of our research, we use Andriessen's (2007) model of Design-Based Research (DBR). Andriessen translates DBR's dual purpose of contributing to theory and to practice into a model that separates research activities in a

'knowledge stream' and a 'practice stream'. Activities in the knowledge stream show resemblance with traditional research activities, and are mainly aimed at developing generalizable knowledge. The objective of the practice stream on the other hand "... is to contribute to the practical concerns of people in problematic situations by solving particular problems in specific circumstances..." (Andriessen, 2007, p. 93). What is important to note is that in our case the practice stream took place in one team of home care professionals. This has led to outcomes in terms of breakthroughs in the workplace and personal learning (see section 4). The knowledge stream relates firstly to the context of Sensire as a whole and aims at generating design principles for supporting self-organized learning at Sensire. Secondly, the knowledge stream yields outcomes in terms of generic knowledge, by reflecting on our detailed research questions (see section 4).

The knowledge and the practice stream consist of several interwoven activities. Figure 2 visualizes the streams and their corresponding activities. A study can start both in the knowledge stream and in the practice stream. In our case, Sensire's client agenda was leading for the start of our research, hence we started in the practice stream. The research phases in Andriessen's model mostly speak for themselves and therefore we will not describe each in detail. Instead, by describing our specific activities in every phase below we hope to provide an example of Andriessen's model in practice.

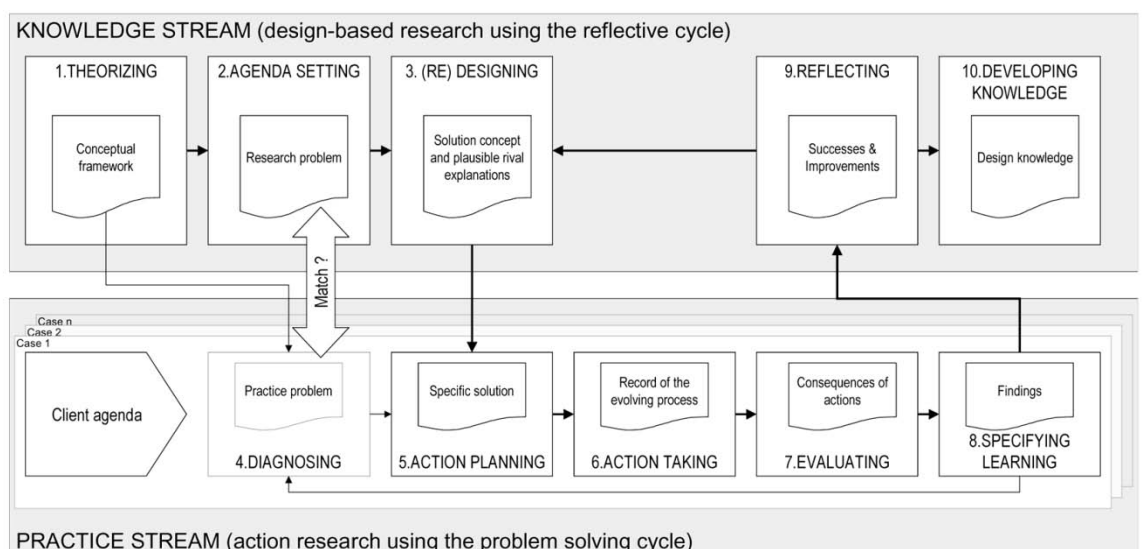


Figure 2: Model of Design-Based Research by Andriessen (2007)

## Preparation phase

### **Practice stream**

#### *Exploring the client agenda*

In order to get to know our clients and to explore their specific problems in their specific situation, we met a first time with an internal consultant responsible for personnel and organization and two of Sensire's managers: the manager 'quality care' and a project leader that is responsible for building the organization's new learning climate. During this meeting the managers explained earlier steps they had taken towards more self-organization, such as reducing team size and positioning care related experts at the center of the teams.

Additionally, they described how they encountered problems in creating a climate in which home care professionals self-organize their learning.

### ***Knowledge stream***

#### *Theorizing*

We drew upon social capital theory, self-determination theory, distributed leadership and appreciative inquiry to develop a conceptual framework of factors that contribute to a learning climate for self-organization (see section 2).

#### *Agenda setting*

Based on the client agenda and the conceptual framework we formulated the central research question (*How can Sensire create a learning climate in which home care professionals self-organize their professional developmental process?*) and detailed research questions based on social capital theory, self-determination theory, distributed leadership, appreciative inquiry and the urgent work-related question (see section 2).

#### *Designing*

In order to find preliminary answers to the research questions, we designed a conceptual framework to study self-organized learning at Sensire (see figure 1). In a project proposal, addressed to the management team, we described the conceptual framework and the research problem, which served to widen our understanding of self-organization at Sensire.

## **Phase 1**

### ***Practice stream***

#### *Diagnosing*

According to Andriessen (2007) a crucial step in the research model is to diagnose the practice problem, and to ensure there is a match between the research questions in the knowledge stream (the detailed research questions) and the research question in the practice stream (the main research question). Exploring this match is an essential activity for supporting the practicality (Nieveen, 2009) of the intervention. In a second meeting with the managers we explored whether our conceptual framework and research problem (described in a project proposal) matched the agenda the managers described to us in the first meeting. The managers unanimously confirmed that the theories and research problem provided theoretical 'language' for the phenomena they observed in their organization, thereby underlining the practicality of our research design.

#### *Action planning*

The phase of action planning involves developing a specific intervention in a specific context for the practice problem. The intervention consists of three stages, each including activities in one home care team. The activities relate to specific detailed research questions. The stages can be seen as a micro-cycle of research. During the research activities, we used field notes to document our observations. We presented these observations to the team and steering group in reflection documents, which were the starting point for formative evaluation. In the practice stream below we will discuss each stage more in depth.

At this point we also selected the participants for our study. The organization asked us to conduct the research within a team that had reached a certain level of team development. This ensured that the team had 'extra hours' they could invest in the project, and still stay within the required 'production limits'. We sent an open invitation to all teams that met the criteria.

Three teams replied positively. Of these three teams, one was immediately available. We were assigned to this home care team of twelve home care professionals to test the intervention. In addition we formed a steering group, consisting of managers and members of the home care team, to reflect on the ongoing intervention and entire research process. Our research focused on one team only, as the steering group members were convinced that most home care teams show great resemblance. To us, additional studies within more teams would have been valuable to support the generalizability of our findings.

Below we describe the stages of our intervention in the practice stream more in depth. For every stage we provide an overview of the activities we conducted, which findings they produced and the way these findings were used to redesign the intervention. In terms of Andriessen's (2007) model these are the steps of 'action taking', 'evaluating' and 'specifying learning'. The lessons learned in each stage can then be used to re-diagnose the practice problem and potentially redesign the intervention.

#### *Action taking: Joining in the work & first team meeting*

The first stage of action taking consisted of two activities. First we joined the home care professionals in their daily work and held appreciative interviews about their passions and strengths. This way we got to know the practice of home care from close-by and were able to detect the team members' specific qualities and problems.

The second activity in this stage was a collective team meeting to identify personal talents and formulate development goals for all team members. This helped in finding preliminary answers to detailed research question 4 (on appreciative inquiry). Next to that, it supported the home care professionals to detect their specific talents, which is the main starting point for professional development from an appreciative perspective. Additionally, we asked the home care professionals what an 'ideal team' would look like that supported their talents and developmental goals. This was aimed at finding preliminary answers to detailed research question 2 on self-determination theory. During this meeting we got to know the home care professionals better and, as we heard afterwards, they've gotten to know each other better as well. This contributed to the collaborative nature of the research. Also we gave specific attention to the relevance and expected practicality (Nieveen, 2009) of the research activities by discussing this with the team members.

During this first phase of action taking we learned there is a difference between the primary individual work context with customers and the activities that concern the entire team. In the context of their (individual) work with the customer, the home care professionals' basic psychological needs autonomy, competence and relatedness were satisfied. The home care professionals felt a strong connection to the customer they take care of and they felt a strong responsibility for the work that needed to be done. They work hard to provide the best care possible and take initiative to develop themselves (e.g. by following courses to increase their technical skills). This also showed during the team meeting where their personal talents and development goals were mainly focused on providing (better) care for their customers. In this context the professionals showed a high level of self-organization.

In the context of team development, we noticed a different attitude. Team development is defined as taking initiative to improve the way team members work together. When it concerns these activities the professionals showed disengagement, aloofness and a lack of initiative. During the team meeting the professionals explained that this stems from the fact that the team

is fully accountable to the organization for their working hours. The primary focus of the professionals is caring for their customers; all work besides this (e.g. scheduling and team meetings) has to take a minimal amount of time. This resulted in a feeling that every hour spent besides the primary process is an hour lost. This possibly thwarts the professionals' need for autonomy and leaves little space for curiosity about things that can help them improve their work as a team. These observations led to the insight that development takes place at two levels, namely the team and individual level.

#### *Evaluating: Reflection document & steering group meeting*

The first stage of action taking was followed by a formative evaluation with the steering group. In preparation of this meeting we wrote an interim report, which describes our research findings based on the first stage of action taking in the home care team. The steering group members recognized the results, and our conclusion that the home care professionals show different attitudes between their primary work and team related work.

#### *Specifying learning*

The evaluation of action stage 1 was a moment of personal learning for the members of the steering group and it increased the relevance (Nieveen, 2009) of the conceptual framework. The steering group members confirmed our adjustment of the conceptual framework, by distinguishing between self-organization at an individual level and at a team level.

## **Phase 2**

### ***Practice stream***

#### *Diagnosing*

Based on our lessons learned in the previous research phase, we re-diagnosed the practical problem as follows: *How can Sensire create a learning climate in which home care professionals self-organize their professional developmental process, both at individual and team level?*

#### *Action planning*

Our experiences in the practice of the home care team so far led to an adjustment of the design of the intervention, in order to increase consistency and expected effectiveness (Nieveen, 2009). The second and third collective team meetings we had planned now focus successively on self-organization at the individual level and self-organization at the team level.

#### *Action taking: Second team meeting*

This second stage of action taking consisted of a second collective meeting with the team. The initial question during this research phase was: what do you want to achieve and who can help you with this? This meeting was set up to improve the home care professionals' bonding, bridging and linking relations that support them in their professional development. Furthermore, we hoped to identify sources of leadership internal to the team that supported leadership functions such as *providing feedback* or *solving problems*. This would help us gain insights in how specific leadership sources contribute to the team's development. Additionally, the meeting was set up to find preliminary answers to detailed research questions 1 (on social capital theory) and 3 (on distributed leadership).

We started the meeting with a reflection on the first research stage. We discussed our findings concerning the professionals' reserved attitude towards team development. They recognized



this attitude and gave two main reasons for it. The first reason is the small amount of time they can spend on work other than to care for customers, as described above. The second reason is that they took initiative in the past to improve their work as a team, which was not recognized by the organization and therefore led to nothing. While discussing this we noticed that the professionals have many questions concerning the improvement of the team, but they don't feel free to discuss these questions and implement possible solutions. Their needs for autonomy and competence are thwarted, causing a lack of initiative on these matters. We decided to refocus the meeting and invited all team members to formulate their three most urgent work-related questions and to cooperatively design a solution. This increased the meetings practicality and relevance (Nieveen, 2009) since these were clearly relevant matters at this point. The meeting now refocused to find preliminary answers to questions 3 (leadership sources) and 5 (urgent work-related question) and to support the home care teams' self-organization related to team development.

During the second team meeting, the team members were concerned with the following urgent work-related questions:

- Creating time to discuss complex issues of specific customers,
- Organizing a collective informal team activity,
- Finding a solution for understaffing, specifically the team lacked home care professionals with specialized skills.

When we invited the team members to design solutions for these questions this resulted in three usable solutions, which they could implement right away.

#### *Evaluating: Reflection document & steering group meeting*

For the formative evaluation of the second stage we wrote a reflection document on the second team meeting and discussed this with the steering group. During this steering group meeting the team coach and two members of the home care team were also present. The team meeting in the second stage provided the insight that the professionals do not feel to have space and time to discuss and work on the things they think are important, but when they are given the opportunity to formulate and work on their urgent work related questions they quickly come up with solutions. The team members explained the factors that limit their space and time to work on such matters. An example is the agenda for the team meetings. The professionals feel obliged to discuss certain topics, because the management wants them to. The response of the steering group members was that they always intended to give the teams as much space as possible and that professionals are free to determine what they want to discuss during team meetings. This interaction was an important step in satisfying the team members' need for autonomy, which led to a breakthrough in the work, because it resulted in a new approach and way of working for both the team and steering group members. It was a moment of personal learning for both the steering group and team members.

#### *Specifying learning*

An important lesson learned during the second research stage was that working from urgent work-related questions satisfies team members' needs for autonomy and competence and subsequently support self-organized learning. Furthermore, during this research stage we learned that a strong bridging relation between managers and team managers is supportive of self-organized learning.

### **Phase 3**

#### ***Practice stream***

##### *Action taking: Third team meeting*

In the third and last stage with the home care team we facilitated another meeting with the entire team. We invited the team members to use their experiences during the research activities and their work in general to draw up principles and tools for how the team and the home care organization can create a learning climate for self-organized learning. This meeting was aimed at finding preliminary answers to all detailed research questions and to work towards a set of principles for supporting self-organized learning at Sensire. To do so we randomly formed two groups and a researcher facilitated each group. Examples of principles that the team members formulated are: (1) make sure to link learning activities to practice, (2) create room for everybody's personal needs, and (3) support good relationship with colleagues. Examples of tools are: (1) informal team meetings, (2) the ability to discuss urgent work-related questions during team meetings, (3) team courses, and (4) joining in each other's work.

##### *Evaluating: Reflection document, final research report and steering group meeting*

For the formative evaluation of the third team meeting we wrote a reflection document and a final research report in which we answered our research questions and formulated design principles. Here the practice stream and the knowledge stream clearly intertwine. The activities in the knowledge stream 'reflecting' and 'developing knowledge' lead to answers to the research questions and design principles. We will describe these in section 4.

In the third steering group meeting we discussed the reflection document and the final research report. An important finding is the expression of the team that they want to be able to do what they think is relevant at a certain point (urgent work-related questions). We discussed this in the meeting with the steering group. The meeting also focussed on reflecting on the actual effectiveness of the research, which was perceived as high. The desired outcomes and the design principles were perceived as very helpful for supporting organizational members to self-organize their learning. During the meeting the steering group and the team coach expressed their struggle with their role in supporting home care teams. They experienced a dilemma between self-organization and decision space for the teams on the one hand and a desire for control and accountability on the other.

Together with the steering group, team members and team coach we determined the next steps in order to dig deeper into how Sensire can create a learning climate for self-organization. An important new area to study is the role of both managers and team coaches in supporting self-organized learning.

##### *Specifying learning*

The most important lesson learned in this final stage is that managers and team coaches experience a persistent dilemma in supporting self-organization within Sensire and that this dilemma needs specific attention during a next study.

#### ***Knowledge stream***

##### *Reflecting: Final research report and steering group meeting*

In a final research report we reflected on the research process and answered our research questions. We provide these answers in section 4.

### *Developing knowledge*

In the same research report we formulated five design principles for creating a self-organized learning climate at Sensire (see section 4).

## **4. Yields of the project**

At the end of section 2 we presented our detailed research questions, based on our conceptual framework. Section 3 described the entire process with the home care team and the steering group. In this section we will present what the main results of our research were in terms of:

- Generic knowledge: *what lessons can be learned from the research? The extent to which these lessons can be transferred to different contexts?*
- Yields in the work context: *what breakthroughs have been realized in the work and by whom? What is visible in practice (new approaches; products; ways of working)?*
- Learning yields: *who has learned what during this research? Who developed what new skills?*
- Design principles for creating a conducive learning environment in Sensire.

### **Generic knowledge**

In this section we summarize the yields of this study in terms of generic knowledge, based on the detailed research questions we formulated at the end of the conceptual framework and the activities 'reflecting' and 'developing knowledge' in the knowledge stream of our research.

#### *1. What kind of bridging, bonding and linking relations can be identified in Sensire and in what way do they support home care professionals to self-organize their learning?*

During the second team meeting we observed bonding relations among the team members that supported them to tackle urgent work related questions. Working on these issues together was one of the factors that made it possible to come up with smart and new solutions for complex problems. Similar to this finding, De Jong (2010) describes "inviting participants" and "connecting the interests of participants" as important steps for networks to be innovative. Next to these bonding relations, we observed bridging relations between team members and managers. These relations were formed explicitly during the second meeting of the steering group. They enabled team members and managers to express mutual expectations and to disprove faulty assumptions or put them in perspective. It also enabled managers to speak out their trust towards team members. This clearly enlarged the team members' space to self-organize their learning and work on team development.

We observed no linking relations in this study.

#### *2. How do the needs for autonomy, competence and relatedness express themselves in the work of Sensire's home care professionals and how can they be fulfilled?*

During the first stage of our research we found that motivation can be viewed at two levels. The first level refers to individual professionals' motivation in the primary process of caring for customers. The second level is the motivation for working as a team and for matters of team development. The three needs of SDT are differently fulfilled on these two levels. In the primary process we observed a high level of autonomy, relatedness with customers and a strong drive to be competent in order to care for customers. In team development there was still room to fulfill the needs for autonomy and relatedness more sufficiently. During our research we found factors that help fulfilling these needs, such as bridging relations and working from an urgent work-related question (see questions 1 and 2).

3. Which sources of leadership can be discovered in and around the team of home care professionals and how do these sources interact with the different leadership functions in order to support a climate for self-organized learning?

During our work with the home care team, we discovered several sources of leadership that clearly influenced the team's leadership functions. In our meetings with the team, the steering group and our own reflections as researchers, we identified several sources that existed in and around the team that clearly influenced leadership functions. In table 2 we present these sources, divided into the four categories defined by Morgeson, et al. (2009). Below, we shortly mention a few connections between the existing sources and team leadership functions. Of course it is also interesting to discuss which expected sources of leadership were absent, but the length of this chapter confines us to the discussion of those sources which were found present.

Table 2: Identified leadership sources related to the team of home care professionals

	Formality of leadership		
	Formal	Informal	
Locus of leadership	Internal	Team 'captain of care'	Team members
	External	Team coach Management	Research team

We noticed that leadership functions that are taken up by sources inside the team (formal: the 'captain of care' and informal: the home care professionals) seem to be carried out more quickly and efficiently. A high amount of influence by the team members themselves increases the capability of the team to cope with changes in the external environment and adapt accordingly. The team members expressed that, with increasing room for self-organization, there wasn't an absence of *leadership practice*. Instead they felt that leadership practice was now becoming more of an internal team affair than an external one. They also remarked that the team's 'captain of care' did not feel like a formal role to them, instead stressing that the team members all felt equal. This said, we did notice that the pressures towards accountability from external formal sources seemed to suppress the room for self-organization for the home care team. The influence of the external formal leadership sources (management and the team coach) could be seen on functions such as challenging the team's practice and supporting them in their development. However, the influences from the formal external sources can also work counterproductively when team members feel they need to account for all of their actions. The factor time also seems to play a role here, as home care professionals can (mis)perceive external forces because of previous experiences. For example, support by a team coach can be viewed as a management intervention instead of a useful tool. In this research project, we as researchers also affected the team's development by drawing them into a researching mode and giving feedback about our observations. The findings described above seem to converge with predictions from prescriptive works on distributed leadership, such as the work of Morgeson, et al. (2009) on team leadership.

4. In what way can an appreciative approach to organizing support self-organized learning at Sensire?

Especially during the first research stage we observed the influence of appreciative inquiry on the ability of home care professionals to self-organize their learning. When asked about their

talents and developmental goals, they quickly and without any direction from others formulated their learning goals and needs. An important aspect if this success is related to the basic psychological need 'autonomy', which has often been proven to support initiative and professional development (Deci & Ryan, 2008). Our appreciative approach during our research in the home care team laid a strong emphasis on autonomy, by questioning the professionals, but never steering them in a particular way.

5. *In what way does an urgent work-related question support home care professionals to self-organize their learning at Sensire?*

The power of an urgent work-related question in self-organized learning and especially for self-organization in team development was clearly visible during the second team meeting. The home care professionals' initial reserved attitude changed quickly after they started working on their urgent work-related questions. This corroborates with the findings of De Jong (2010). Next to the urgent work-related question, a second factor that motivated the professionals and enabled them to create smart solutions was the practical approach of this meeting. Instead of only talking about solutions, the professionals actually created them. In line with this conclusion, Verdonschot (2009) found that the principle of "creating something together" is of great importance to be innovative.

**Yields in the work context**

In this section we describe several breakthroughs that were realized in the work context and by whom.

*Home care professionals developed a stronger ability to self-organize learning and team development.* At the start of our research all team members showed high levels of self-organization in the primary process of caring for customers. During our research the team members were invited to self-organize matters of team development as well. This invitation has changed their attitude towards team development matters from disengaged and aloof to enthusiastic and initiative.

*Stronger bridging relations between management and team coaches, between management and team members and between team coaches and team members.* These bridging relations led to an improvement of team members' ability to self-organize internal team development matters, as was visible in their innovative work during the second and third team meeting. These stronger bridging relations also led to an increased awareness of managers that their efforts to support teams' self-organization do not always work out as they intend. Certain regulations and tools are meant to help teams to become more self-organized, but teams may experience them as restrictive. Perhaps the most important lesson both team members and management learned was to stay connected in order to improve organizational development.

*Solutions for three urgent work-related questions.* Next to these abstract breakthroughs, three concrete breakthroughs have been realized during the second team meeting with home care professionals, when we actively worked on solutions for urgent work-related questions. The topics were: time to discuss complex issues, an informal team activity and understaffing of specialized skills. The team members created these breakthroughs by themselves. Our role was to facilitate by clarifying their statements and supporting them to create an actual solution.

### **Who learned what: Personal learning yields**

The most important and most striking learning yield of our research is an increased awareness of the home care professionals of their talents and added value. During the first stage in which we joined the team members in their work, they showed high modesty about their work. The most heard sentence was: *This is normal, it's part of my work*. At the end of our study the home care professionals explained that the appreciative nature of our research supported them to put their talents to work (see section 4, question 4).

### **Design principles**

At the end of our research we formulated the following five design principles that are supportive of a self-organized learning climate within Sensire.

*Reflect on matters that are important to you.* There is no blueprint for creating a conducive learning climate for self-organization. Therefore it is most important to develop an ability to constantly reflect on matters that are important to you and your work, and acquire new knowledge and skills if necessary. A home care professional expressed this design principle as follows: "It is not about a set of tools that we can deploy in any situation, but about constantly asking ourselves the question: *are we still doing the right thing?*"

*Start from urgent work-related questions.* During the second team meeting we have vividly experienced the value of urgent work-related questions. An urgent work-related question supports motivation and enthusiasm, appeals to autonomy and can quickly lead to smart and sustainable solutions. It is motivating if activities that professionals undertake are closely related to practical urgency. This urgency is not only found in external pressure, such as an assignment, but is also related to personal commitment to that urgency (Verdonschot, 2009). In order to be innovative, it is highly important to pay attention to formulating urgent work-related questions (De Jong, 2010).

*Create something together.* After formulating an urgent work-related question, it is highly attractive to actually do something about that question, to create a concrete solution for it. Verdonschot (2009) refers to this as "creating something together". This makes it important that there is room for professionals to formulate and work on their urgent work-related questions, for example during team meetings.

*Work and learn from an appreciative and inquiring attitude.* For the team members our appreciative and inquiring attitude towards their work and personal development, helped them to self-organize their learning because it helped them reflect on matters that are important to them. Appreciative inquiry means looking for what is possible, asking questions that encourage deeper thinking, express appreciation for colleagues, creativity and autonomy and create space for everyone to take influence.

*Work on relations between colleagues.* Relations, both bonding relations in one team and bridging relations between teams and between teams and management, are supportive of creating a climate for self-organized learning. Strong relations enable people to help each other to fill in their new role and to express mutual expectations. In addition it fulfills the need for relatedness and therefore stimulates intrinsic motivation for learning and development.

The steering group expected these design principles to be applicable to other teams of home care professionals at Sensire as well, since their situation is highly comparable to the situation of the team where we conducted our study.

## 5. Lessons learned

We have learned first and foremost that working together with practitioners on questions that they perceive as urgent can create enthusiasm and engagement with the project. In this regard, the research project strengthens our belief that people inherently care about their work and want to contribute to improve on it.

We used the scientific theories to guide our observations, which allowed us to systematically look at the situation within the team. The selection of theory and the way we used it to describe daily practice in a different way than Sensire's 'insiders' are used to, inspired the steering group. The steering group was very positive about our contribution, because it offered a refreshing glance inside the company. At the moment of writing Sensire's management and team coaches are working on next steps, which are tied directly to the content of our work. To us, this means that the research project has been able to get important next questions to the surface that Sensire can now work on.

In our view DBR - and specifically the model of Andriessen (2007) - has been proved useful for a consultancy trajectory in the context of organizational learning. Often consultancy trajectories focus solely on the practice stream. A DBR approach helps to incorporate scientific theories into the design of a consultancy trajectory. In return the insights from the trajectory can be used to reflect on the scientific theories.

The study was conducted with one home care team, therefore the generic knowledge and design principles are specific for this team and at best generalizable to Sensire's department of home care. In the health care sector, similar to the field of education, a large number of professionals is active and similar issues such as professional space and self-organization play a role. Therefore yields from our study are interesting for educational practitioners and researchers who concern themselves with self-organized learning in teams.

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Tim Hirschler (1986) started out on the path of psychology, but his mind was set more towards improving organizational practice and development. Tim now studies Human Resource Development at the University of Twente, where he is able to 'get his hands dirty' and concern himself with organization's questions. At the moment, Tim is professionally entangled in a mix of design research, entrepreneurship and writing a master's thesis. His primary interests go out to distributed leadership, self-organization and their relationship with an innovation of practice. Some questions that busy him are: How can employees put their skills and expertise freely to work in organizations? Why is self-organization so hard to pin down, yet so attractive an idea? And which leadership configurations will we see in the future, when this process, too, becomes more decentralized? The distributed leadership concept speaks to his imagination not only because it seems such powerful analytic tool, but also because it gives language to phenomena we see but cannot 'catch' with classical person-oriented views of leadership. In addition, working with distributed

leadership presents a good challenge. Precisely this challenge sparked Tim's interest in design research; which feels very much like the 'right kind of middle way' in designing, doing and researching.

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Frank Hulsbos (1982) studied Educational Studies at the University of Amsterdam. After he graduated he started working as a self-employed consultant and researcher. His work focuses on creating contexts in which professionals are able self-organize their work and professional development. In doing so, he is inspired by the ideas of distributed leadership and self-determination theory. Distributed leadership emphasizes that leadership is not limited to formally assigned managers, but is rather a mutual process between individuals that claim and grant influence. Self-determination theory views human beings as active and growth oriented organisms that need to experience autonomy in order to be fully engaged in activities. These theories provide theoretical language to understand and further support people's drive to direct their own lives. Next to his consulting and research practice he is attached to the University of Twente as a guest lecturer in the master track Human Resource Development. For more information see [www.frankAuthor3.nl](http://www.frankAuthor3.nl) and [www.distributedleadership.nl](http://www.distributedleadership.nl) (both in Dutch).

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Stefan van Langevelde (1989) received his bachelor degree in Psychology at the University of Twente. The research described in this chapter provided the data for the final thesis of the bachelor programme. At the time of writing he is working on his final thesis for the master degree in Human Resource Development at the University of Twente. His main drive is looking at how theory can help the practice of organizations to keep developing themselves and their employees. He is specifically interested in how theories on self-organizing, motivation and leadership can help organizations in creating a learning environment and stimulating innovation in the workplace. In the research for his master thesis he works as a consultant for organizations with questions around these topics. He uses these cases to investigate the relationship between self-determination theory (motivation), distributed leadership and knowledge productivity (innovation).

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## Improving Curriculum Developers' Formative Evaluation through an Electronic Performance Support System

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Credits



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# 51. Improving curriculum developers' formative evaluation through an electronic performance support system

Nienke Nieveen

## Abstract

*Exemplary learning and teaching materials play important roles in curriculum change processes. This is especially true during initial implementation stages when such materials can demonstrate the practical meaning of the change. Ensuring the quality of learning and teaching materials is, to a large extent, the responsibility of curriculum developers. During the development process they should give attention to evaluating and improving the quality of their products. However, in many contexts, there is a lack of thorough formative evaluation activities. This contribution reports on a four-year design research study on an electronic performance support system (EPSS) that supports developers of lesson materials in their formative evaluation efforts. After an extensive front-end analysis, four prototypes of the system (called CASCADE) were created and evaluated on the basis of their validity, practicality, and effectiveness. This design research study led to a twofold result. At first a computer support system CASCADE that assists in: improving the consistency of formative evaluation plans and activities; elevating developers' confidence in using formative evaluation activities; saving time by providing adaptable examples that reduce the need for starting from scratch; and providing justifications for decisions made. Moreover, the study led to a set of design principles for the development of similar EPSSs. This chapter provides details about the way this design research study was conducted in the mid-1990s. At the end of the chapter a 'flash forward' offers newly gained insights in support of curriculum developers' formative evaluation.*

## 1. Introduction

Exemplary lesson materials play important roles in curriculum change processes (cf. Ball & Cohen, 1996). This is especially true during initial implementation stages when such materials can serve various functions that include: (a) demonstrating the practical meaning of the change; (b) providing opportunities for potential users to experiment with the materials to gain insights into the implications of the change in their daily practice; and (c) encouraging discussions about the changes among teachers who are using the materials.

To fulfill these functions, the materials must be of high quality and developers should give great attention to evaluating and improving the quality of their products. However, in many contexts, there is a lack of thorough formative evaluation activities. Fullan (1991, p. 52-53) points out that "*.. too often the innovations are not 'debugged' and lack the clarity and program characteristics necessary to help users know what to do*" and (in 2007, p. 91) "*decisions frequently are made without the follow-up or preparation time necessary to generate adequate materials*".

This flaw was also discovered in the practices of SLO Netherlands Institute for Curriculum Development. SLO (staffed by about 100 employees) carries out many curriculum development projects for elementary and secondary education at the national, school and classroom level. The lesson materials have only an exemplary, not obligatory, status. Schools and teachers are free to use these products and to adapt them to their own needs and situations. A study on the development practices of a representative sample of 18 completed SLO projects showed that curricular decisions were predominantly inspired by ideas (visions) and were insufficiently based on evaluative information about their quality in practice (van den Akker, Boersma, & Nies, 1990). This result stimulated a debate within SLO about the possibility of rationalizing its development processes. Because of its overwhelming variety of actors, ideas, interests, and contexts, it seemed undesirable to 'over-rationalize' or even to standardize the entire process of generic curriculum development. Eventually there was little disagreement that a combination of creativity, common sense, and systematic procedures would be necessary to improve product quality and process efficiency. It was assumed that several components of the process could benefit from specific new procedures and instruments.

In the early 1990s, SLO initiated a series of paper-based manuals as a support for its curriculum developers. One of these manuals covered the domain of planning and conducting formative evaluation of lesson materials. Although the first reactions of SLO staff to this kind of information were rather positive, there was also some reluctance to accept the rather static nature of the written guidelines and instruments. It was felt that a more flexible and interactive kind of support would increase the added value of the manual. This need was related to a general increase of interest (from the early '90s) in the use of electronic performance support systems (EPSSs). Instead of presenting different kinds of (paper-based) support separately, an EPSS provides integrated information, advice and learning opportunities to improve the users' performance (Gery, 1991; Hudzina, Rowley, & Wager, 1996; Raybould, 1995; Jonassen & Wilson, 1990).

Thus, an initiative arose to explore the possibility of a computer-based version, leading to a follow-up study in the front-end analysis. The following EPSSs that were available at that time were identified and characteristics were analyzed: AGD (Paquette, Aubin, & Crevier, 1994), ID Expert (Merrill, 1993), ID Library/IDioM (Gustafson & Reeves, 1990), ILCE (Valcke & Vuist, 1995), COCOS (Rosendaal & Schrijvers, 1994), CEDID (Flehsig, 1989), GAIDA (Gettman, 1994), and QUEUE (Laws & Howell, 1994). For an extended review of the attributes of these systems, see Nieveen, (1997), and Nieveen and Gustafson, (1999). After analyzing these EPSSs, interviewing the developers and reviewing relevant literature, it was found that these systems could lead to: (a) improved task performance by stimulating a more structured development approach and encouraging the internal consistency of design decisions; (b) improved instructional development knowledge because less experienced developers can use the system to familiarize themselves with parts of the development process; and (c) promotion of organizational learning by making knowledge and experiences more explicit. Results of this exploratory study showed that none of the available systems specifically focused on the formative evaluation of lesson materials.

In order to gain experience with developing a computer-based support system for curriculum developers, an initial EPSS on formative evaluation was designed. This resulted in a set of tentative design recommendations for such a system.

As a result of this front-end analysis, the CASCADE (Computer Assisted Curriculum Analysis, Design and Evaluation) study was initiated in 1993.

The main research question was: "What are characteristics of a high quality computer support system for formative evaluation of lesson materials within the SLO context?" The project was to lead to a high quality computer support system and design principles that carry rich information on key characteristics of the intervention and suggestions on how to design similar interventions for similar settings.

The remainder of this contribution comprises the research design of the prototyping stage, an account of two of the prototyping stages, the conclusions of the CASCADE study and a reflection on the current situation concerning the formative evaluation efforts of SLO.

## 2. Research design

In fact, few people would dispute the importance of developing high quality products for the educational setting. Nevertheless, quality criteria remain often implicit, which complicates not only the discussions about the quality of a product, but also the way high quality products could be developed. During the CASCADE study a framework for product quality was elaborated in order to understand and apply a more thorough approach to develop the product. The quality criteria have been linked to the typology of curriculum representations (Goodlad, 1979; adapted by van den Akker, 2003). For further information on the notion of product quality, please refer to Nieveen (1997; 1999) or to the chapter on formative evaluation in part A of this book. Three criteria were used to define the quality:

- *Validity* The computer support system CASCADE should be based on 'state-of-the-art knowledge' and should be internally consistent.
- *Practicality* CASCADE should meet the needs, wishes and contextual constraints of the members of the target group (the curriculum developers) and should be well usable in the target context.
- *Effectiveness* CASCADE should impact the formative evaluation efforts of the target group.

This clarity in quality criteria supported the communication between the developers of CASCADE, the stakeholders and target group. Interaction among these groups appeared to be of paramount importance as it was difficult for all of these groups to provide detailed specifications for the CASCADE system in an early stage of the project. Not only was the type of support that the target group needed largely unknown, it was also difficult to decide which aspects of formative evaluation should be included in the support system and which characteristics the user interface should have. In such cases, when there are many uncertainties, it is recommended to allow the specifications to evolve using a prototyping approach (Shneiderman, 1992; Tessmer, 1994). Prototypes are all products that are designed and subsequently are evaluated before the final product is constructed and fully implemented in practice. Moreover, a prototyping approach could be made even more transparent, when decomposing the product into several key components (de Hoog, de Jong, & de Vries, 1994). The CASCADE system was decomposed into three such components. The first component was the *content* of the system, referring to the conceptualization of the formative evaluation of lesson materials. The *support* included in the system in order to assist the target group in performing a formative evaluation of the lesson materials they are developing was viewed as the second key component of CASCADE. The third key component was the *user interface* that should assure that the support is accessible for its users. In a good user interface users are not aware of using the interface in order to get the support they need.

Each of these components could contribute to or obstruct the overall effectiveness of CASCADE. Therefore, the three quality aspects (validity, practicality and effectiveness) were considered to be requirements for each key component of the system (content, support and user interface). In addition, the whole system should show coherence between its key components.

In order to develop an high quality support system (and thus in order to answer the main research question), four subsequent prototypes of CASCADE have been developed (as depicted in Table 1). Each prototype focused on at least one quality criterion from which the specific research question(s) related to the prototype were derived.

- Paper-based prototype: In order to illustrate the potential of computer-support, without the need to put much effort into actually programming the support system, a set of papers representing the screens that may appear during the use of the system was developed. This prototype focused especially on the system's content (the conceptualization of formative evaluation of lesson materials) and the practicality of the support and user interface. The evaluation questions were: *"What is the validity of the content as proposed in the paper-based prototype"* and *"What is the practicality of the support and interface as proposed in the paper-based prototype?"*
- First computer-based prototype: Based on the formative evaluation of the paper-based prototype and the design ideas collected, a first computer-based prototype was constructed that focused on the validity of the interface and the practicality of the system as a whole. The evaluation questions were: *"What are the validity and practicality of the user interface of the first computer-based prototype?"* and *"What is the practicality of the entire first computer-based prototype?"*
- Second computer-based prototype: Based on the promising results of the formative evaluation of the first computer-based prototype, the decision was made to continue building it until the second computer-based prototype was ready. This prototype focused on the validity of the support and again on the practicality of the entire prototype. The following evaluation questions were raised: *"What are the validity and practicality of the support of the second computer-based prototype?"* and *"What is the practicality of the entire second computer-based prototype?"*
- Final version: Based on the formative evaluation results of the latter prototype, it was decided to rebuild the prototype in order to obtain a final version that would be compatible with the Windows-platform used by the intended target group. The summative evaluation questions were: *"What are the practicality and effectiveness of the final version of CASCADE?"*

Table 1: Focus of design and formative evaluation of the prototypes

		Paper-based prototype	First computer-based	Second computer-based	Final version
Validity	Content	- expert appraisal			
	Support			- expert appraisal	
	Interface		- expert appraisal		
Practicality	Content		- cooperative evaluation	- cooperative evaluation	- workshop - tryout
	Support	- walkthrough	- cooperative evaluation	- expert appraisal - cooperative evaluation	- workshop - tryout
	Interface	- walkthrough	- expert appraisal - cooperative evaluation	- cooperative evaluation	- workshop - tryout
Effectiveness	Entire system				- workshop - tryout

Note:  = primary focus of prototype

Although each prototype forms an integrated whole, each individual prototype had its own central focus. Evaluation questions for each prototype were based on the stage of development (paper-based, first computer-based, second computer based prototype, final version) and the central focus (validity, practicality and effectiveness) of each prototype.

As is illustrated in Table 1, depending on the evaluation questions, five major formative evaluation methods were chosen: walkthrough, cooperative evaluation, expert appraisal, workshop and tryout.

- Expert appraisal: Expert appraisal was chosen in order to gather comments by interviewing experts on the validity of various prototypes and seek expert advice about the practicality of certain key components of the prototype. The experts who participated in the formative evaluation of the user interface were scholars in the field of interface design. The experts who participated in the evaluation of the content and support were selected based on their expertise in the field of curriculum development and, more specifically, formative curriculum evaluation.
- Walkthrough: The walkthrough was used in order to answer the second question regarding the paper-based prototype. During the walkthrough, members of the user group went from one paper screen to another while the designer of the prototype took the role of the computer. For instance, when a user "pushed" a button to go to another screen, the designer showed the user this screen, which was another paper in the pile.
- Cooperative evaluation: During the cooperative evaluation users worked through a set of tasks with the system. The tasks were representative of the formative evaluation activities that the system will support. If necessary, the designer of the prototype assisted the user. The need for this type of cooperation provides an indication that revision decisions may be required. The walkthrough and cooperative evaluation gave members of the user group an opportunity to judge the practicality of various prototypes and to provide suggestions for improvement. They also led to empirical information on the actual practicality of the prototype.
- Workshop: A four-hour hands-on workshop was held to introduce CASCADE to a larger audience of SLO developers and to get insights in the system's practicality and effectiveness.
- Tryout: In order to gather indications about the practicality and effectiveness of CASCADE in real practice, the system was used by a purposive sample of four SLO developers in their projects.

In order to give a central role to the members of the target group during the discussions about the growing ideas and prototypes, a user group of five SLO representatives was recruited. They were to differ with regard to the following aspects:

- department of the SLO in which they work (two developed materials for primary education; three for secondary education);
- experience with formative evaluation (two had relatively much experience; three had relatively little experience);
- basic computer skills: two were relatively skilled; three had relatively little skills.

On a voluntary basis these representatives participated in the walkthrough and cooperative evaluation activities.

### **3. From tentative design ideas to a final version**

Based on the front-end analysis, some tentative design ideas were generated concerning the content, support and user interface of CASCADE (see Table 2).



Table 2: Tentative design ideas for CASCADE

<b>Content</b>	1. As formative evaluation is a research activity performed in order to improve the quality of the lesson materials, it should start from evaluation questions and the research activities should be chosen in such a way that they answer these questions.
	2. As formative evaluation needs to be seen as an integrated activity in the development process of lesson materials, the evaluation approach should recognize the focus of the evaluation in each stage.
	3. As developers themselves need to be responsible for carrying out formative evaluations, attention should be paid to formative evaluation activities that are realistic.
<b>Support</b>	1. The surplus value of the computer should be visible compared to, for instance, a paper-based handbook.
	2. As the support system is meant for professional curriculum developers who wish a relatively large degree of freedom, the users of the system need to maintain control over their own activities and remain responsible for them
	3. As the support is meant for developers who are not automatically experts in formative evaluation who know when to use which tools in which ways, the provision of the support should not be arbitrary
<b>Interface</b>	1. The system should be useful for a heterogeneous group of curriculum developers, therefore the system should be user friendly, i.e. special attention should be given to a transparent screen design and flexible navigation.

A full description of how these tentative ideas transformed into a final version of CASCADE and its accompanying set of final design principles is presented in Nieveen (1997). Due to the shortage of space in this chapter, only the prototypes and evaluation activities of two stages will be elaborated: paper-based prototype and the final version. For both instances first a description of the prototype will be provided, followed by the research design of the evaluation and the results.

### **Paper-based prototype**

#### ***Brief description of the paper-based prototype***

The main concern in the early design steps was how to illustrate the surplus value of CASCADE compared to, for instance, a paper-based handbook. It was expected that these illustrations would require considerable programming capacity. Putting too much (programming) time into the elaboration of ideas which in the end may appear not to be practical was viewed as a potential problem. For this reason, a paper-based prototype was designed first. The paper-based prototype consisted of a set of papers representing all screens of the preparation stage of a formative evaluation. Users could 'walk through' the screens. Because such paper-based prototypes are relatively easy to produce and to change (compared to software prototypes), Rettig (1994) advocates employing these prototypes in early design stages, when many design decisions are still open. In this section, the design decisions concerning the content, support and user interface of the paper-based prototype of CASCADE are discussed briefly.

#### ***Content (paper-based prototype)***

The content of CASCADE refers to the conceptualization of formative curriculum evaluation. Within the paper-based prototype, the concept of formative curriculum evaluation was defined

as an activity which is integrated in the curriculum development process, which aims at reducing uncertainties about a design of a (part of a) curriculum and eventually aims at generating decisions based on which the quality of the curriculum could be improved. Moreover, in this conceptualization, the following quality aspects were distinguished:

- *Acceptability* refers to the question as to whether experts agree on the theoretical foundation of the intended curriculum and its internal consistency and whether the way prospective teachers interpret the curriculum corresponds to the developers' intentions with the materials. The concept of acceptability was divided into the following three questions:
  - Do the curriculum components (rationale; aims and objectives; subject matter; modes of transaction; and learner evaluation) meet the requirements?
  - Does the curriculum show internal consistency between all curriculum components?
  - Do the teachers accept the curriculum?
- *Practicality* refers to the ability of prospective teachers to carry out the curriculum as intended by the developers.
- *Effectiveness* refers to whether the learners experience the curriculum as intended and the results learners demonstrate with respect to the intentions of the developers.

The evaluation approaches (screening, expert appraisal, micro-evaluation and field test) were determined by the three uncertainties with respect to the lesson materials and the stage of development of the lesson materials, i.e. design specification, tentative development, partially detailed materials, detailed materials, or final deliverable. The following stages were distinguished within an evaluation activity: a. preparation, b. data collection, c. data processing, d. reporting, e. revision. It was decided to focus the paper-based prototype on the preparation stage (stage a).

The preparation stage (a) included the following sub-stages: 1. description of the context; 2. formulation of the evaluation questions; 3. decision on evaluation approaches; 4. selecting activities; and 5. selecting and/or developing instruments.

#### *Support (paper-based prototype)*

The paper-based prototype was built to illuminate various ways in which the computer may support the curriculum developer in preparing a formative evaluation. This prototype included various templates.

Three templates were added which concerned the match between: evaluation questions and evaluation approaches; evaluation approaches and evaluation activities; and evaluation activities and evaluation instruments.

Another option was included through which users could choose whether they would like to adapt an existing instrument or to develop a new instrument. When users chose to adapt an existing one, CASCADE would show the instrument in a word processor. When the users wished to develop a new instrument, the system would open a new text-file. For each instrument, CASCADE provided procedural guidelines and points of attention on how to develop selected instruments. Explanation of concepts, references and examples related to each aspect of the formative evaluation were mentioned but were not yet elaborated. All information stored in the system could be used again later on in the project.

#### *User interface (paper-based prototype)*

All support belonging to each sub-stage was brought together in one screen. Although this led to more information on each screen, it was assumed that it would help in getting a better overview of each sub-stage. Figure 1 provides the screen design of sub-stage a1 "Description of the context".

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**Description of the context** (Preparation stage)

The context of the formative evaluation comprises of the following characteristics:

- |                                                        |                                                  |                                                    |                                                    |
|--------------------------------------------------------|--------------------------------------------------|----------------------------------------------------|----------------------------------------------------|
| <b>Stage of development</b>                            | <b>Uncertainties</b>                             | <b>Constraints</b>                                 | <b>Importance</b>                                  |
| <input type="checkbox"/> Design specification          | <input type="checkbox"/> acceptability           | <input type="checkbox"/> ample sources             | <input checked="" type="checkbox"/> very important |
| <input type="checkbox"/> Global development            | <input checked="" type="checkbox"/> practicality | <input checked="" type="checkbox"/> little sources | <input type="checkbox"/> less important            |
| <input checked="" type="checkbox"/> Partially detailed | <input type="checkbox"/> effectiveness           |                                                    |                                                    |
| <input type="checkbox"/> Detailed                      |                                                  |                                                    |                                                    |
| <input type="checkbox"/> Final deliverable             |                                                  |                                                    |                                                    |

This context description could be used to formulate the evaluation questions. If you wish to formulate the questions now, please click on:

- evaluation questions

start	former screen	next screen	main map		explanation of concepts	references	examples
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Figure 1: Example of a screen of the paper-based prototype

Special attention was given to a clear screen design in order to minimize cognitive overload. To make more flexible use of the system possible and, in the meantime, to provide a clear overview of the content of the system, a map was added containing a matrix with the stages and the sub-stages. Each sub-stage was presented as a button. When users double clicked on a sub-stage button, they would go to that sub-stage. Each screen gave access to this map. Users did not always have to use the map to navigate through the system. They could also follow an 'ideal' line through CASCADE offered by the 'next' button on each screen.

**Formative evaluation and revision decisions (paper-based prototype)**

For the paper-based prototype, the evaluation questions were: "What is the validity of the content as proposed in the paper-based prototype" and "What is the practicality of the support and interface as proposed in the paper-based prototype?" In order to answer the first question, experts in the field of curriculum development and formative curriculum evaluation were invited individually to give their comments and suggestions during an expert appraisal. The walkthrough with a number of lesson developers was used in order to answer the second question regarding the paper-based prototype. The remainder of this section will elaborate on both the walkthrough and expert appraisal.

*Walkthrough by the user group*

The walkthrough method was used to gain insight into the practicality of support and user interface of CASCADE. During the evaluation, the user group (n=5) 'walked through' the paper-based prototype by going from one paper screen to the other guided by three scenarios of possible usages of CASCADE. Each scenario included a series of screens that should give the user an idea of events that could happen when they would consult CASCADE. In the first scenario, the participants started at the beginning of the prototype and gained an impression of the screens that they would see when they would use CASCADE linearly. The second scenario showed that users could also begin somewhere else in the system (for instance, at the

instruments). The third scenario dealt with the situation in which the users decided to start at the screen with the instruments but did not know which instrument to choose. This scenario showed how CASCADE could provide advice in such situations. Each user was asked to work aloud, which made it possible for the evaluator to determine problems and comments concerning the support and user interface. To assure that all questions concerning the paper-based prototype would be answered by all users, a checklist was used. During a plenary meeting the results from the individual judgments were summarized and discussed. Based on this, revision decisions were made.

Members of the user group appeared to appreciate the support and user interface of the paper-based prototype. With respect to the support the following decision was made:

- In order to make using the support quicker and to the point, unnecessary steps should be avoided. For instance, instead of providing an option for generating main evaluation questions, CASCADE could present these questions automatically, based on the context description. The only thing users have to do is verify or adapt the proposed questions.

The following decisions were made with respect to the user interface:

- To make the navigation easier for first time users, information about the navigation should be included in a help function.
- It should be made clearer on what aspects users can get explanation, references, examples and advice.

#### *Expert appraisal*

Expert appraisal was chosen to gain insight into the validity of the content of CASCADE. Three experts in the field of curriculum development in general and formative evaluation in particular received an outline of the conceptualization of formative evaluation. Based on the outline they provided comments on the correctness and internal consistency of the conceptualization. In addition, these comments were discussed with each individual expert. It appeared that the experts were rather positive about the correctness and internal consistency of the content of CASCADE. Most comments were requests.

For more specifics on certain topics, such as:

- In the definition it was not clear what kinds of activities are included in the formative evaluation.
- It was not clear who is responsible for determining the requirements of the lesson materials.

Also, some changes were suggested with regard to:

- the distinction between formative evaluation stages, for instance: the actual development of instruments should be done after the preparation of the formative evaluation has led to the conclusion of which instruments will be needed;
- the table for selecting suitable evaluation approaches, for instance: it is not possible to perform a micro-evaluation with materials which are in a global stage of development, as was suggested in the outline, because in this stage the materials are not yet sufficiently elaborated to be usable in practice.

The feedback of the experts was taken into account in a subsequent version of the conceptualization. This version was discussed in a plenary meeting with these and some additional experts. None of those experts suggested any major changes or additions. This led to the conclusion that, for that moment, the content of CASCADE was acceptable according to participants in the expert appraisal.

## **Final Version of CASCADE**

Based on the characteristics of the content, support and user interface of the paper-based prototype and the results of the formative evaluation, a first and later a second computer-based prototype were designed and evaluated. A computer-based prototype approximates the actual support and user interface (for details on both computer-based prototypes, please refer to Nieveen, 1997). Building on the formative evaluation results of the second computer-based prototype it was concluded that CASCADE only needed some fine-tuning. This led to the decision to work toward a final version. The remainder of this section will describe the final version and its accompanying summative evaluation activities.

### ***Brief description of the final version***

#### *Content (final version)*

During the development stages of the system, the validity and practicality of the content of CASCADE (i.e. the conceptualization of formative curriculum evaluation) grew to a large extent. Based on comparing and synthesizing the definitions of various scholars in the field of formative evaluation and experts' feedback, the following aspects of formative curriculum evaluation are emphasized in CASCADE:

- It is a systematically performed activity that is integrated in the development process.
- It aims to determine the quality of lesson materials and generating ideas for improvement by judging the validity (deciding whether it is based on 'state-of-the-art knowledge' and whether it is internally consistent), the practicality (whether the materials are usable in the settings for which they have been designed) and the effectiveness (whether using the materials result in desired outcomes).
- It includes four main stages: preparation, data gathering, data processing and reporting. The content of each stage depends on factors such as: the stage of development of the lesson materials; the quality aspects on which the developer will focus during the formative evaluation; the facilities of the project and the role of the developer. Developers decide on the type, scope and sequence of the (sub) stages.

The fact that it was possible to let the conceptualization evolve with each prototype, helped in gaining a better understanding of possibilities of formative evaluation in complex curriculum development projects.

For instance, the fundamental requirement that CASCADE needed to be practical for professional developers who usually have to deal with a lack of time and resources, largely stimulated the reflection on efficient and realistic formative evaluation. This led to the understanding that performing a field test would not be feasible for a developer who wants to do a formative evaluation. It was considered to be more helpful to suggest small-scale evaluation approaches (which take into account the time and resource problems) and assist developers in applying these approaches in a meaningful and consistent way. Developing various support components of CASCADE encouraged the process of making the implications of the content explicit. Particularly the development of the templates and interactive advice components demanded a clarification of the interrelationships between various aspects of formative evaluation. For instance, to be able to provide interactive advice on suitable evaluation approaches, the links should be clear between stages of development of the lesson materials, quality aspects, evaluation questions and available facilities to do a formative evaluation.

#### *Support (final version)*

CASCADE provides computer-based job aids to assist curriculum developers in preparing and performing formative curriculum evaluation activities. The attributes of the support were largely

based on the needs and wishes of the user group. For instance, the members of the user group indicated that they would be especially interested in using a computer-based support system if it would assist in (instead of automating) their task performance. In addition, the support system should include potential advantages of the computer, such as adapting and storing files, and providing interactive advice based on user input.

Because professional curriculum developers wished to have a large degree of freedom in user support, considering CASCADE to be a toolbox appeared to be helpful. The system provides several tools (templates, instruments and frameworks) to assist developers in planning and conducting a formative evaluation. Users are free to decide whether they will use or adapt the tools. The cookbook is another metaphor that fits CASCADE to some degree. This refers to the idea that the support system also takes into account the wishes of developers who appreciate more detailed assistance in selecting suitable tools, using the tools properly, locating efficient formative evaluation activities, and ways to carry out these activities. To assist these individuals, CASCADE provides heuristic support, including advice, automatic delivery of a framework, procedures, conceptual explanation, and reminders.

#### *User Interface (final version)*

The user interface of CASCADE should assure that the support of the system is accessible for a heterogeneous group of professional curriculum developers. Figure 2 provides an example of the screen design of the sub-stage "Context description" of the preparation stage.

With respect to CASCADE, principles were gathered from user interface literature and the formative evaluation findings of this study:

- All support that belongs to each sub stage of formative evaluation is provided on a single screen.
- Support remains "out of the way" until the developer asks for it.
- All screens have several screen areas, each with its own function and located in the same position on the screen throughout the system.

To clarify the navigation and to make the use of the system flexible, the system was given the following characteristics:

- Assistance in finding the location by providing a task map and a "You are here" screen area.
- Possibilities to use the system in a linear manner or to make cross references using the task map or "You are here" screen area.
- Use of graphical objects: buttons and hot words to make links to additional support or to other parts of the system and check boxes to clarify which options are chosen.

Figure 2: Example of a screen of the final version

### Summative evaluation of the final version

The main evaluation question with respect to the final version was: "What are the practicality and effectiveness of the final version of CASCADE?" The evaluation of the final version consisted of two components: a workshop and tryouts. The workshop was planned to gain an indication of the practicality and effectiveness of CASCADE for a wider group of SLO developers. Because the performance of a complete formative evaluation is a complex activity, it was decided that the workshop would focus on one part of a formative evaluation: the preparation stage. The tryouts, however, were planned in order to study the practicality and effectiveness of CASCADE during an entire formative evaluation cycle in actual practice.

### Workshop in SLO

The central question of the first study of the assessment stage was: "What are the practicality and effectiveness of CASCADE during the preparation of a formative evaluation within SLO practice?"

The practicality of CASCADE is considered to be conditional for its effectiveness.

This means that if CASCADE does not meet the needs and desires of SLO curriculum developers, the chance that the system will have any impact on the formative evaluation efforts of SLO developers will be small.

For that reason, the practicality of the content, support and user interface of CASCADE needed to be studied first. Further, CASCADE is considered to be effective, if developers in the SLO target group are able to develop evaluation plans; if developers of the evaluation plans are satisfied with their plans and with the preparation process of their plans; if developers do not require too much assistance from other individuals during the construction of the plan; and the production of the plans does not take too much of the developers' time.

In order to introduce CASCADE to a larger group of SLO developers (i.e. larger than the user group involved in the prototyping stage) a four-hour hands-on workshop was planned. A built-in log function in CASCADE saved the actions of the participants. The workshop leader and an assistant interfered with the process only when the participants raised problems or comments and made notes of the comments and support they provided.

All 65 SLO developers were invited to attend the CASCADE workshop on a voluntary basis and 17 accepted the invitation. The group of 17 who participated was considered to be representative of the SLO population with respect to their development experiences (12 experienced developers with four or more years' experience in curriculum development and 5 starting developers with less than two years' experience in development activities) and with respect to their experience with planning and performing formative evaluation. The construction of an evaluation plan, as it is proposed in CASCADE, was not a routine part of the professional activities of most participants. A majority of the participants (n=9) indicated that they sometimes do a formative evaluation without having a plan. Only six participants indicated that their plans usually contain evaluation questions. This is noteworthy because such questions are viewed as cornerstones of an evaluation.

The findings of the workshop show that the support system seems to be practical for the heterogeneous group of 17 SLO developers. The preparation stage of a formative evaluation flowed rather smoothly and all participants were able to construct a first framework of a formative evaluation plan. It is important to note that developers with little experience in planning a formative evaluation were able to construct frameworks that were quite similar to those constructed by more experienced planners. Also, the use of CASCADE made developers with little experience in planning formative evaluations more confident about their ability to plan. Most participants expected that the support system would lead to less conceptual confusion between team members and that they would make more use of earlier experiences and documents. Moreover, most participants agreed that the support is task centered and they appreciated the guidance of CASCADE during the preparation stage. This could be illustrated by comments of participants, such as: "*CASCADE is a clearly structured and guiding program. In my opinion it is especially suitable as a checklist in order not to skip any steps in the process of formative evaluation.*", and "*It opens up your horizon in case you are stuck.*"

#### *Tryouts at SLO*

To gain insight into the practicality and effectiveness of CASCADE in real practice, tryouts were planned with four SLO projects that conducted a formative evaluation of lesson materials for primary or secondary education. The research question that guided the tryouts was "*What are the practicality and effectiveness of CASCADE during the performance of formative evaluation activities within the SLO practice?*"

Practicality refers to the extent the key components of CASCADE (content, support and user interface) meet the needs and desires of the SLO developers. CASCADE was considered to be effective if it led to an entire formative evaluation cycle: (a) about which participants were satisfied; (b) that did not require too much external support; (c) that did not take too much time of the participants; and (d) that led to revision measures, which, in turn, impacted the lesson materials or the underlying intentions of the developers for the materials.

The project members agreed to use CASCADE as much as possible during their formative evaluation activities. The evaluator of CASCADE was allowed to intervene with the process only in cases in which problems were indicated by the participants. The participants were asked to



make notes in a logbook about a number of relevant aspects such as the components of CASCADE they used; the practicality of the components; satisfaction with the process; the time needed to complete a task; support they received from others; and the impact of the evaluation. With the help of a log tool, the computer kept track of CASCADE's use. Interviews of about one hour were conducted after the participants had finished a clear-cut part of the formative evaluation. The topics that were discussed during the interviews were based on the issues raised in the logbook.

Based on these data, a report of the tryout was written for each project. These reports were further summarized, leading to an overview of the tryout results and outlines of the major tryout results for each participant. Participants were invited to check their outlines (which led to some minor changes).

The results of the tryouts reflected the problems and opportunities of projects in daily practice. Despite the willingness of the participants to carry out a formative evaluation while using CASCADE, only one out of four projects completed the formative evaluation activities. The three other evaluations were ended early on because of policy changes, delay of the project, and communication problems. It can be concluded that making firmer agreements on the importance of formative evaluation activities in an early development stage may influence the actual performance of these activities. The project leader who did succeed in performing the formative evaluation especially appreciated the preparation stage with its interactive advice. According to her it is important to put much effort into preparing an evaluation, because this effort helps to clarify what to ask and what to look for. In the end, a good preparation of the evaluation appeared to be of real support for her during the data gathering and processing stage. Although she only had a little time, money, personnel and expertise to do the formative evaluation, she was able to integrate the formative evaluation activities into her development project.

The findings of the tryout provide an indication that CASCADE is practical and possesses the potential to be effective in projects of the SLO. However, it should be stressed that providing a support system to developers will never guarantee the performance of effective formative evaluations.

#### **4. Conclusions and 'flashing forward'**

The design research study CASCADE started with the main question "*What are characteristics of a high quality computer support system for formative evaluation of lesson materials within the SLO context?*" The study was to lead to a prototypical computer support system and generate design principles for the development of similar products.

Table 3: Summary of main design principles

<p><b>With respect to the content</b> Tentative design ideas</p>	<p>... and additions based on the study</p>
<p>1. As formative evaluation is a research activity performed in order to improve the quality of the lesson materials, it should start from evaluation questions and the research activities should be chosen in such a way that they answer these questions.</p>	<p>Evaluation questions need to be based on the development stage of the lesson materials (design specification, tentative development, partially detailed materials, detailed materials, or final deliverable) and the quality aspects (validity, practicality and effectiveness) that are to be studied. These questions determine the evaluation approaches.</p>
<p>2. As formative evaluation needs to be seen as an integrated activity in the development process of lesson materials, the evaluation approach should recognize the focus of the evaluation in each stage.</p>	<p>As design attention and evaluation questions shift from validity to practicality to effectiveness; evaluation activities need to shift accordingly from informal small scale to more formal and larger scale activities.</p>
<p>3. As developers themselves need to be responsible for carrying out formative evaluations, attention should be paid to formative evaluation activities that are realistic.</p>	<p>Developers of lesson materials need to get suggestions for small-scale evaluation approaches (which take into account possible time and resource constraints) and developers need to be assisted in applying these approaches in a meaningful and consistent way.</p>
<p><b>With respect to the support</b> Tentative design ideas</p>	<p>... and additions based on the study</p>
<p>1. The surplus value of the computer should be visible compared to, for instance, a paper-based handbook.</p>	<p>Make sure that the system assists in (instead of automates) the task performance of the curriculum developers and include potential advantages of the computer, such as adapting and storing files, and providing interactive advice based on user input.</p>
<p>2. As the support system is meant for professional curriculum developers who wish a relatively large degree of freedom, the users of the system need to maintain control over their own activities and remain responsible for them.</p>	<p>Give users freedom to decide whether they will use or adapt the tools (Toolbox metaphor) Give users who appreciate more detailed assistance in selecting suitable tools, using the tools properly, locating efficient formative evaluation activities, and ways to carry out these activities (Cookbook metaphor)</p>
<p>3. As the support is meant for developers who are not automatically experts in formative evaluation who know when to use which tools in which ways, the provision of the support should not be arbitrary.</p>	<p>Provide task-centered support that is connected to the sub-stages of formative evaluation.</p>

Table 3: Summary of main design principles (continued)

<b>With respect to the user interface</b> Tentative design ideas	... and additions based on the study
1. The system should be useful for a heterogeneous group of curriculum developers, therefore the system should be user friendly, i.e. special attention should be given to a transparent screen design and flexible navigation.	Take care of a transparent screen design: <ul style="list-style-type: none"> <li>• Provide all support that belongs to each sub-stage of formative evaluation on a single screen.</li> <li>• Keep support "out of the way" until the developer asks for it.</li> <li>• Provide screen areas on each screen, each with its own function and located in the same position on the screen throughout the system.</li> </ul> Put flexible navigation in place: <ul style="list-style-type: none"> <li>• Assist in finding the location by providing a task map and a "You are here" screen area.</li> <li>• Provide a task map or "You are here" area to make linear and flexible use possible.</li> <li>• Use graphical objects (buttons and hot words) to make links to additional support or to other parts of the system and check boxes to clarify which options are chosen.</li> </ul>

The main characteristics of the final version of CASCADE have been described in section 3 of this chapter. Based on these characteristics for each component of CASCADE (content, support and user interface) a set of design principles was composed for EPSS designers who intend to design a similar system (see Table 3).

The findings of the study demonstrated that the final version of CASCADE is valid and practical and concerning its effectiveness indications were found that the system assists in:

- Improving the consistency of the formative evaluation plans and activities, because it structures the decisions and assists in considering several explicit options.
- Making developers feel confident in doing the formative evaluation themselves, because it provides overviews of explicit options.
- Saving time, because it assists in constructing a framework of a formative evaluation plan in a short time period and it provides adaptable examples that reduce the need for starting from scratch.
- Improving the justifications for the choices, because it presents conceptual explanations.

Moreover, the results of the study also showed that the support system CASCADE should be seen as an intervention among others. To bridge the lack of expertise and tackle misconceptions, staff development activities are needed that focus on the conceptual background of efficient formative evaluation and strategic planning of such evaluations. The introduction of CASCADE should be a part of such a learning trajectory. Also non-educational interventions are needed. For instance, project managers should motivate developers to perform a formative evaluation by providing positive feedback on formative evaluation efforts, and/or by providing additional sources (personnel, budget or time) for formative evaluation.

The CASCADE study was considered to be a first exploration of the use of computers in the field of formative curriculum evaluation in the context of SLO. Based on the findings of this study the scope was broadened and the system was adapted to other contexts: sub-Saharan Africa (CASCADE-SEA; McKenney, 2001, see also Mckenney and Reeves in this volume), China (CASCADE-MUCH; Wang, 2001) and Indonesia (CASCADE-IMEI; Zulkardi, 2002). For a full account, please visit the website <http://projects.gw.utwente.nl/cascade/>.

### **Flashing forward...**

The CASCADE study was carried out in the mid-1990s. What happened between then and now within SLO? Interestingly, the lack of formative evaluation interwoven in development activities of SLO appeared to be rather persistent. In 2006 another study was carried out in order to determine the status quo concerning evaluation practice within SLO (Gervedink Nijhuis, Nieveen, & Visscher-Voerman, 2006). Regrettably, CASCADE was never fully implemented nor used in SLO. Moreover, findings showed that, although some evaluation activities were carried out, the repertoire of the evaluation methods applied was still narrow. Most of the time focus group activities were organized, in which teachers were asked to react to an intervention; other more suitable methods were hardly applied. It was surprising, the extent to which the results of this study corresponded with the findings of the case studies carried out in the 90s, also regarding the lack of policy within SLO to really make a difference with respect to integrating formative evaluation in development processes.

The persisting problem of neglecting the potential of formative evaluation was for SLO in 2005, when a new board was installed, reason to invest structurally in changing this situation. This was done by introducing a set of interventions linked to the professional development of curriculum developers in SLO.

- Design of evaluation matchboard (see also the chapter on formative evaluation in part A of this book) and a web-based tool based on CASCADE ([leerplanevaluatie.slo.nl](http://leerplanevaluatie.slo.nl) (in Dutch));
- Professional development (especially workshops) to build developers' capacity in evaluation;
- Development of various guidelines for planning and performing evaluation;
- Installation of an evaluation-team consisting of senior researchers with experience in the field of evaluation to support curriculum developers in planning and performing formative evaluations.

Moreover, SLO invested in improving its curriculum development culture by:

- Continuous communication about the importance of evaluation for curriculum development, using various channels and media (internal memos, articles, news items on the intranet, and meetings with the department managers).
- Inviting board members and heads of departments to facilitate, motivate and appreciate good practices.
- Providing extra budget for performing evaluations.

In 2009, this set of interventions has been evaluated with SLO developers. In conclusion, SLO appeared to be on track towards a situation in which curriculum developers integrate formative evaluation activities into their development processes. However, it remains to be a balancing act between trusting the professionals on the one hand and pressuring these professionals to change their working habits on the other hand. Support systems like CASCADE can enable this process, but can never be held responsible for the more comprehensive change needed.

Future design researchers interested in designing and studying comparable systems are advised to make sure that their studies are well-embedded in a context that takes care of the other changes needed, including organizational change, in order to increase the chances of making a difference.

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