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Didactics as Design Science

- peer reviewed papers from a PhD-course at the University of Copenhagen

Carl Winsløw
Robert Evans

January 2010

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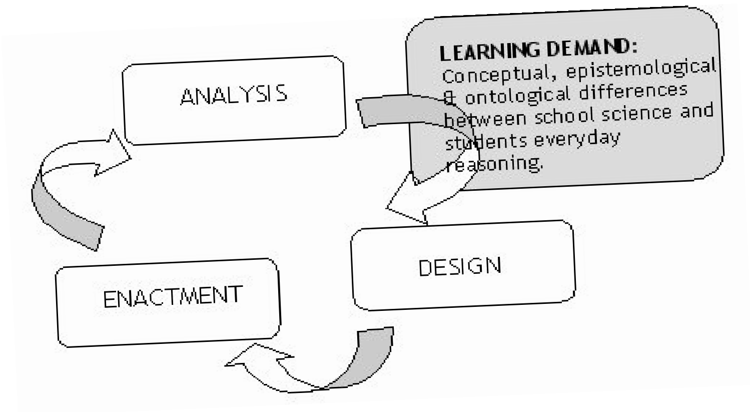
DIDACTICS AS DESIGN SCIENCE



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A GRADUATE COURSE ON DIDACTICS AS DESIGN SCIENCE

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THE THEME

Didactics is the science which investigates the conditions for teaching and learning. These conditions may arise from a number of sources: societal and institutional (from outside the teaching/learning system), cognitive and social (from teachers and learners as interacting individuals) and epistemological (from the knowledge at stake). When we talk about didactical design, none of these factors can be entirely ignored, but it is undeniable that the knowledge itself – and the ways it is prepared, presented and indeed transformed, in order to be taught – lends itself most directly to design. Modalities in and principles for this may well present regularities that allow for stable modelling of the didactical design process; but whether it is so cannot be determined *a priori* but must necessarily be learned from an inductive process, involving the patient study of concrete systems with particular forms of knowledge, particular learners and teachers, and particular institutional and societal contexts. Even after accepting this, we are left with a variety of forms that this study could take, from the passive, descriptive study based on simple observation of teaching as it occurs "naturally" (if one may ever talk of nature in this setting), to active, experimental studies of teaching-learning systems set up with the deliberate purpose of testing particular hypotheses or approaches. And, whatever kind of approach we adapt, we need theoretical frames to sharpen our questions, observations and interpretations of what we observe.

The idea of this course has been to examine a range of newer approaches – and theories – adopting the more active view on the phenomena of teaching and learning. The term "design science" is often used to describe such approaches, since teaching-learning systems are indeed cultural constructions rather than natural phenomena. Simon (1969, 55f) is one of the first to situate *education* among the design sciences:

> Historically and traditionally, it has been the task of the science disciplines to teach about natural things: how they are and how they work. It has been the task of engineering schools to teach about artificial things: how to make artifacts that have desired properties and how to design… Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law and medicine, are all centrally concerned with the process of design.

So, while the "hard sciences" are concerned with "what is", the "nature of things" existing more or less independently of us, design sciences are concerned with "what may be", to develop methods to study and control the "invention of things".

A design science needs to answer questions such as:

• What does it mean for a design to « work » (according to criteria which are both « valid » and « transparent »)

• What methods can be used to develop designs that will « work ».

This requires theoretical frameworks and empirical methods to go beyond arbitrary experiments – at any rate, we usually cannot test « all » possibilities.

The complexities of teaching-learning systems are often cited as a basic difficulty, due to the variety of conditions which were already mentioned. Whenever we deal with complexity, scientific study necessitates certain reductive assumptions to begin with, but unlike the natural sciences, we can usually not reduce complexity to the point of having complete reproducibility of our experiments: the trade-off between complexity and precision is usually "harder" if we are still to obtain meaningful results. And so, paradoxically, the "soft sciences" are faced with harder conditions when it comes to identifying a meaningful, yet manageable object of study:

> The 'hard sciences' are successful, as they deal with 'soft problems'. The 'soft sciences' are badly off, as they are confronted with 'hard problems' (Forster, 1972, 1).

The "hard" requirements, which stem in the end from the expectation that our results are not only meaningful but also useful, are of course shared with any branch of, say, engineering.

Indeed, the idea to look upon the study of teaching-learning systems as an engineering science has been present in European didactics since the early seventies, perhaps most notably through the works in didactics of mathematics (see, for instance: Wittmann, 1974; Brousseau, 1982; Chevallard, 1982). The theory of didactical situations (Brousseau, 1997) is one of the sharper paradigms which have resulted from pursuing this idea of *didactical engineering*, where design is a method more that a result of research (cf. Artigue, 2009).

More recently, a similar but also different Anglo-American tradition in mathematics education research has emerged, in part as a reaction to the « what works » model of educational research, to do *research-based development of tools and processes for use by practitioners* (Burkhardt & Schoenfeld, 2003; quoted in Artigue, 2009). The two main ideas can be summarised through the following agendas:

• *design experiments* as *extended (iterative), interventionist (innovative and design-based), and theory-oriented enterprises whose "theories" do real work in practical educational contexts* (Cobb et al., 2003);

• *design tasks* to get *research evidence* of common student reasoning and the associated *learning demand* with respect to a given target knowledge; then, design of teaching intervention (Scott, Leach, Hind, Lewis, 2006).

The associated theoretical frameworks focus on *social* and *cognitive* aspects of the functions of designs, typically in « real » classes (although more clinical types of experiments also occur). At the same time, we see the emergence of interactions with the European tradition, such as the theory of didactical situations (Brousseau, 1997).

THE COURSE

This course posed itself the ambitious goal of inviting its participants into the plurality of these developments right from the first session of the course. Concretely, we were very happy to present internationally renowned lecturers, each representing a main current approach to design research in mathematics and science education:

- Professor Isabelle Bloch from the University of Bordeaux, who offered a three hour workshop on designs and methods resulting from work within the theory of didactical situations, centred from the beginning in Bordeaux;
- Professor John Leach from the University of Leeds, whose three hour workshop provided an in-depth experience with the communicative approach to learning design developed in his research group in Leeds.

In addition, Berta Barquero (Autonomous University of Barcelona) offered a lecture on didactical design research based on the anthropological theory of didactics and in particular the programme of “Research and study courses”.

In preparation for the first session, the participants read the texts listed in Appendix 1. Many of these texts appear as references in the papers of this book, showing the importance of the first session in establishing common ground for the work to follow.

All three sessions of the course spanned two full working days. During the second session, the main activity consisted in discussions of individual participants’ projects, based on further literature listed in Appendix 2 and distributed after the first session. We note that two natural subgroups formed the basis for the work in this session, as the participants were almost evenly distributed between science and mathematics education.

The third and final session of the course took the form of a “conference” in which preliminary forms of the papers in this booklet were presented.

After the third session, a *peer review process* (with participants acting as anonymous reviewers for each other) as well as scientific editing (by us) was organised to refine the papers for publication in this booklet. Not all 14 participants chose to participate in this final, optional part of the course, but the nine papers offered here are representative of the best that was produced in the highly friendly and creative atmosphere to which all participants contributed throughout the course.

Thus, the course as a whole aimed at reproducing, to the extent possible, a genuine research process from early preparations through to final publication. Indeed, it was a main explicit goal of the course that the participants would develop a research activity related to their own doctoral project, and also to the theme of didactics as design science, to the point of producing a real research paper before the third and final session. Clearly, the extent to which this goal is reasonable depends both on the stage of the individual participant's project, but all papers in this booklet are the results of what we see as satisfactory progress – and in fact, some are already in the process of being developed into ordinary journal papers.

THANKS

We finally present our heartfelt thanks to all 14 participants for the enthusiasm and energy they put into this course. Also, our sincere thanks are due to our guest lecturers, Isabelle Bloch, John Leech and Berta Barquero, for their generous contribution to the launching session of the course. We hope that discovering the riches of this volume – and the links with what they offered – will provide them with the reward that we were not able to offer them in financial terms. Finally, we are thankful to FUKU, the Graduate School of Education at the University of Copenhagen, for the support offered to cover travel and other expenses linked to the course, and hence to make this course possible.

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ON THE CONCEPT OF DOCUMENTATIONAL ORCHESTRATION

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Taking as a basis the concepts of instrumental orchestration (Trouche, 2005a) and documentational genesis (Gueudet & Trouche, 2009), in this paper I try to articulate the concept of documentational orchestration. I argue that especially in mathematics teacher education is worthwhile to develop this concept because it addresses the problem of designing activities for teachers, offering a particular way of observing some of the effects or consequences of a particular design, an also a way of guiding the refinement and improvement of such design. This guide is based on the location and observation of the instrumentalization and instrumentation processes that may take place during the application of a particular design. The utilization of the concept is illustrated through the application of an orchestration in an Internet-based teacher education program.

INTRODUCTION

The concept of *documentational genesis* (Gueudet & Trouche, 2009) is a new theoretical concept that seems to be a useful analytical tool for studying the development of mathematics teachers. The concept of *documentational genesis* can be considered as an analogy of the concept of *instrumental genesis* (Rabardel, 1995; Trouche, 2005b) into the field of mathematics teacher education. In this new approach the focus is on the activities that the teacher develops outside the classroom, but that influence his work in the classroom. In particular the focus is on the *documentation work* of the teacher, i.e. the interaction of a teacher with a set of elements that shape and define his work in the classroom; for example, to draw examples and exercises out from a textbook for his mathematics lesson plans, to look up his own notes of previous courses, to analyze the mathematical productions of his students, to listen to suggestions or criticisms of his fellow teachers and his students, to study a curriculum reform to be implemented in his school, etc. This set of elements with which the teacher interacts in order to carry out his documentation work is called *resources*.

There are situations where the interaction between mathematics teachers and resources is not spontaneous. In these contexts there is a need for organizing and arranging the set of resources that the teachers interact with, in order to develop specific aspects of their professional knowledge. Here I am referring to the in-service mathematics teacher education programs. Inspired by the concept of instrumental orchestration (Trouche, 2004; Trouche, 2005a), the aim of this paper is to illustrate and to argue that at least in the field of mathematics teacher education, it make sense and is relevant to use and to develop the concept of documentational orchestration. I will highlight the necessity of studying in a joint way this concept together with the concept of documentational genesis. Particularly it is shown how the instrumentalization and instrumentation processes that constitute a documentational genesis, can be taken as a basis to guide the refinement and redesign of an orchestration. The empirical evidence supporting the arguments are taken from an *online* educational program for mathematics teachers, that is to say, the structure and operation of the program is based on the use of the Internet and its associated tools.

SOME THEORETICAL CONCEPTS

Documentational genesis

The work of Gueudet & Trouche (2009) suggests a way to "trace" the professional development of mathematics teachers. To achieve this, the authors suggest to focus our attention on the sort activities that teachers develop outside the classroom. The focus should be particularly centered on teacher's *documentational work*; that is to say, the interaction of a teacher with a number of elements that allow him to shape and to define his work in the classroom. The set of elements that a teacher interacts with during his documentational work is called *resources*. Resources can be constituted by elements of a different nature such as textbooks, web pages, personal notes, a particular piece of software, a talk with a fellow teacher, student responses to a mathematical task, and so on.

In this new approach it is claimed that when a teacher interacts with a set of resources a *documentational genesis* (DG) may occur. The concept of DG can be considered as an analogy of the concept of *instrumental genesis* (Rabardel, 1995; Trouche, 2005b) applied in the field of mathematics teacher education. Like the instrumental genesis, a DG is also a two-way process in which a teacher appropriates and/or modifies the set of resources that he is interacting with (this part of the process is called *instrumentalization*), but also the resources shape and influence the activity of the teacher (this part of the process is called *instrumentation*). Thus, through a DG the teacher can develop a *document* from the set of resources he interacted with.

An example of a *document* is presented in Gueudet & Trouche (2009, p. 205). In this example a teacher faces a particular *class of professional situations* (Rabardel & Bourmaud, 2003), namely, "propose homework on the addition of positive and negative numbers". After looking at several resources such as textbooks and a list of exercises that she has used in previous courses, the teacher builds a new list of tasks that she uses in her classroom. The list of tasks could be modified by the teacher after seeing how it works in her classroom, and might even be reused in a new group of students or during the next school year. After looking at this example one could interpret that the document created by the teacher is the list of mathematical tasks that she produced, however a document is not necessarily a physical entity.

A document is a mental scheme (also called *scheme of utilization*) that is associated with a specific set of resources (in the previous example, the textbooks and the exercises list she consulted) that guides and defines teacher's actions for a given class of situations (in this case, to propose homework about the addition of positive and negative numbers), through different contexts (the group where she applied the list of tasks and the future possible groups and courses where she could reuse the list of tasks). In the example mentioned above, the list of tasks is just a visible part of the constituted document. There are other non-visible elements that guided and determined the selection and design of the tasks that the teacher listed. Those elements are beliefs and implicit values that drive and lead teacher's action; Gueudet & Trouche (2009) mention an example of these non-visible elements: the idea that "the additions proposed must include the cases of mixed positive and negative numbers, and of only negative numbers".

Thus, a document is associated with a specific set of resources and is composed of a visible and tangible part called *usages*, and an implicit and non-visible part called *operational invariants* (Vergnaud, 1998). A document can then be expressed by the following formula:

Document = Resources + Usages + Operational Invariants

Due to its implicit nature, the operational invariants can not be observed directly. They can be inferred from the prolonged observation of teacher's action. The identification of regularities in the teacher practice across different contexts can facilitate the inference and interpretation of the operational invariants that guide the practice.

Instrumental orchestration

In the instrumental approach it is claimed that the schemes of utilization have a social dimension. It is said that the schemes of utilization are developed and shared in communities and may be even the result of explicit training processes. Thus, it is necessary that these "explicit training processes" could be carefully designed to encourage the establishment or modification of schemes of utilization. It is in this point where the concept of *instrumental orchestration* appears. It refers to the organization of the artifactual environment, which an institution designs and puts in place, with the main objective of assisting the instrumental genesis of individuals (Trouche, 2005a, p. 210).

A instrumental orchestration is defined by two elements (Trouche, 2005a, p. 211):

- A set of *configurations* (i.e. specific arrangements of the artifactual environment, one for each stage of the mathematical situation);
- A set of *explotation modes* for each configuration.

Documentational orchestration

Let's move now to the mathematics teacher education context. This is a context where teacher educators have a set of goals or educational purposes, but they also have a set of resources to try to achieve those goals.

In this context is important to explicitly discuss what the pursued objectives are, and whether the different arrangements or accommodations of the resources are appropriate to achieve those goals. It is here where I find relevant to introduce and to use the concept of *documentational orchestration* (DO). A DO can be defined as an arrangement or accommodation of resources that a teacher educator (or a group of teacher educators) performs with the intention of facilitating and encouraging the documentational work of mathematics teachers, aiming at contributing to the development of their professional knowledge. In principle, the structure of a DO should include the two elements that define an instrumental orchestration, i.e., configurations and exploitation modes. These two elements must be defined in terms of the possibilities and limitations of the educational setting where the orchestration will be applied; it has to be also taken into account the type of knowledge we want to produce.

I think the concept of DO can help us to discuss in an explicit and organized way the relations between pursued aims and the arrangement of resources. In addition, an DO can be refined or redesigned through the identification of the instrumentalization and instrumentation processes that might occur during the implementation of the orchestration.

I will illustrate the application of the concept with an example that has been designed for and implemented in an internet-based in-service teacher education course. In order to design a documentational orchestration it is necessary to specify the environment in which the orchestration will be organized as well as the aim of the orchestration. In the next section I refer to those two elements.

AN EXAMPLE OF A DOCUMENTATIONAL ORCHESTRATION

About the setting where the orchestration was applied

The documentational orchestration was applied in an internet-based educational program for in-service mathematics teachers. This is a program[3] based in the *Instituto Politécnico Nacional* of Mexico. The program offers a master degree in mathematics education (two years). The technological nature of this program has helped to eliminate temporal and geographical barriers, allowing teachers from all over Latin American to have access to this educational program.

To implement the courses that constitute this educational program, is used *Moodle* (http://moodle.org). This is a free and open source platform that allows you to arrange courses by storing and sharing different types of files (such as text, audio and video files), but also permits to organize asynchronous discussions among the participants of a course. An asynchronous communication is the one that is carried out mainly by means of an exchange of written messages between two or more people, but the answers or reactions that the participants get are not immediate, for example, you can raise a question or an observation and get the feedback or reactions to it several minutes or hours after. The asynchronous discussions usually last several days, allowing the participants to have more time to formulate their opinions and to reflect on comments and opinions expressed by the other participants. It is even possible to consult external sources in order to enrich and clarify a discussion in an asynchronous communication. The email messages and the discussion forums are some examples of asynchronous communication.

The aim

The data used in this paper were taken from a course on the use of technology for the teaching of the mathematics. The course lasted for four weeks and it was carried out during November and December 2008. The course was attended by four mathematics teacher educators and fourteen mathematics teachers coming from Mexico and Argentina. The main objective of the orchestration was to make teachers aware of the possible modifications or changes that the tasks and the techniques can experience when technology is introduced in the mathematics classroom as a study tool. We were particularly interested in teachers noticing that a) new techniques may emerge, i.e., techniques that rely on the use of technology, and b) that some tasks and techniques could lose its meaning and become obsolete. Along the course and also in this writing the terms *tasks* and *techniques* are used in the sense of Chevallard (1999).

Didactical configuration

Here I refer to the specific arrangements of the resources with which the teachers interacted during the course. The configuration was aimed at promoting teachers' awareness about the possible effects that produces the use of technology on mathematical tasks and techniques. The configuration is divided into five stages. Figure 2 shows a graphical representation of such configuration.

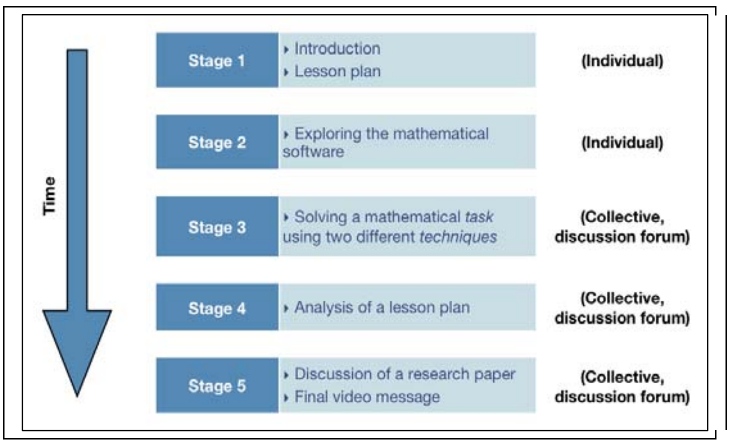

Figure 2: Graphical representation of the didactical configuration.

The concepts of task and technique are the guiding structure of the configuration. The configuration rests on locating those two elements in a math lesson plan designed for a paper and pencil environment (stage 1), and reflect and discuss about their pertinence in a mathematics software environment (stage 4). The discussion about the pertinence should take place after teachers themselves experience some instrumented techniques (stages 2 and 3). The last layer of the configuration is an 'institutionalization' stage.

In **stage 1** an introduction to the course was done. Teachers were notified that the structure of the course was based on the concept of praxeology (see Chevallard, 1999), and by means of an example the components of a praxeology were illustrated. The example used describes a teacher who introduces in her class the topic "quadratic functions". One of the *tasks* that the teacher presents to her students is to "find the roots of $f(x)=ax^2+bx+c$" To solve this *task* the teacher presents a particular *technique* to her students, consisting in applying the quadratic formula: $x_{12}=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$. The teacher explains how to interpret the terms a, b and c of the previous expression. She also shows through examples, that it is always possible to determine the roots of the quadratic function by applying the formula. This speech that the teacher uses to introduce and to illustrate the use of the *technique*, is called *technology*. Thus, some students can successfully apply the technique, but probably they do not understand why the formula always works. The mathematical theory that explains and supports the operation of the technique, and that probably at this stage of their education exceeds the mathematical understanding of students, is what is called *theory*.

The first activity of the course for the teachers was to locate a mathematical topic that they have already taught or that they liked to teach. Afterwards they should identify the type of tasks and techniques that they usually present to their students when they introduce the mathematical topic. This lesson plan was requested at the beginning of the course, to avoid any influence of the contents of the course on their lesson plans.

The course was intended to use a piece of mathematical software. Teachers were provided with a copy of this software. In **stage 2** which lasted three days, teachers were solving specific mathematical tasks using the software. The secondary objective of the activity was to help teachers become familiar with the software, but particularly with the CAS and graphical capabilities of the tool.

The **stage 3** was inspired in the work of Mounier and Aldon (1996) presented in Lagrange (2005). Teachers were organized in teams of four or five members, and then each team was asked to be split into two sub-teams. Both sub-teams should find a general factorization for the expression x^n-1, but one team should only use paper and pencil, while the other one should only utilize the command *Factor* from the mathematical software. At the end of the stage both sub-teams should share their results and to discuss which technique was better to solve that sort of mathematical task. The conclusions of the each team conclusions were presented in a written report. Both the solution of the mathematical activity and the discussion of the results were collectively carried out in an asynchronous discussion that lasted seven days. The secondary objective of this stage was to allow teachers experience different techniques and discuss their differences, advantages and disadvantages. Teachers were expected to highlight the pragmatic value of techniques (Lagrange, 2005), for example, the speed and efficiency with which the software makes the factorization. But it was also expected that teachers (and particularly those who worked with the command *Factor*) recognized some kind of epistemic value in the instrumented techniques.

Stage 4 and stage 1 are linked. During the fourth stage one of the lesson plans that teachers prepared in stage 1 was selected. A lesson plan was selected concerning the solution of systems of linear equations in two variables. The proposed tasks were to find the solution of different systems of linear equations, and the offered techniques were the addition, substitution and graphical solving methods (using only paper and pencil). I was authorized by the teacher who wrote this lesson plan to use it as part of the stage 4.

In this stage teachers were divided into teams and each team was assigned to an asynchronous discussion forum. The selected lesson plan was presented to them in the discussion forum, together with the following hypothetical situation: "There is a mathematics class where students are allowed and know how to use the mathematical software used in stages 2 and 3. If you apply the selected lesson plan in such mathematics classroom and students start to use the software for solving the mathematical tasks, then what kind of effect does technology have on the tasks and techniques included in this lesson plan?" The secondary objective was to highlight some of the effects that technology may have on mathematical tasks and techniques. For example, some of the proposed techniques will become obsolete, because there will be other (instrumented) techniques that would do the work in a more quickly and efficient way. If they perceived this, then it was also expected that teachers felt the need for redesigning the lesson plan in order to implement it in a setting supported by the use of technology.

The **fifth** stage was a moment of institutionalization of the contents of the course. The teachers and teacher educators who participated in the course discussed in an asynchronous forum the content of the research paper Lagrange (2005). It was initially planned to focus the discussion of the paper on the modifications on tasks and techniques that the author of the paper reports. Additionally, a video message was published. In this message the secondary objectives of each one of the activities that integrated the course were explicitly mentioned. This video served as a mean to bring into an explicit level all the ideas that were implicitly involved in the prior stages.

Exploitation modes

The exploitation modes refer to the possible adjustments of the variables of the established configuration. These adjustments should be guided by the intentions of the designer or teacher educator, and also by the purpose of the orchestration. For example, in the configuration previously presented different exploitation modes are possible:

- The configuration privileges the study of CAS and graphical techniques. Adjustments on the mathematical activities of stages 1 and 2 would allow us to shift the focus to techniques and tasks related to dynamic geometry or spreadsheet software, for example.

- In the stage 4, it is not compulsory to have a lesson plan designed by a teacher. The lesson plan can be planned in advance to suit the intentions of the designer. In this way we could cover the analysis of a variety of tasks and techniques suitable for different educational levels.

- The interaction of the teachers with a teacher educator is another variable of the configuration. The collective stages 3, 4 and 5 allow the participation of teacher educators in the discussion forums. A teacher educator can help to promote, to moderate and to guide the discussion; nevertheless sometimes is convenient to establish a discussion where teachers engage in a discussion that is free of the authority of the teacher educator.

DISCUSSION

The concept of documentational orchestration enables us to bring into an explicit level the sort of knowledge (or document) that we want to produce, and the way in which the resources are organized in order to reach that aim. One could argue that this explicit and orderly way to analyze the arrangement of resources and its relation to the aim of the design could be accomplished without using the concept of documentational orchestration, but this is not a concept that should be considered in isolation. The theoretical strength of the concept lies in its connection with the concept of documentational genesis. We can not use the concept of documentational orchestration without making reference to the documentational genesis concept.

A documentational orchestration is regulated and evolves through the feedback that is obtained during its application. This ‘feedback’ is represented by the instrumentation and instrumentalization processes that are manifested in different stages of the orchestration (see figure 1). Let me introduce two examples of the manifestation of those processes:

Example 1, an instrumentalization process. The following is an excerpt from an asynchronous discussion forum from stage 3. In this forum a Mexican and an Argentinean teachers are trying to find a general characterization for the algebraic expression $x^n - 1$. The Argentinean teacher mentioned that she has been implementing

Ruffini's rule during her explorations, and then her Mexican colleague asked her in what book he could find Ruffini's rule. This is the answer to that question (the real names of the teachers have been replaced to protect their identity):

> *Topic*: Re: Team 2. "Paper and pencil technique"
> *From*: Norma
> *Date*: Wednesday, 26th of November 2008, 00:09
>
> Nice to meet you Homero, how are you?
>
> You might already know the Ruffini's rule (as we call it here [in Argentina]) but with another name, it is a shortened way of solving divisions having the form P=(x) / (x+-b) […] To be consistent with this course, I will not recommend you any books, I give you the link to a youtube video.
>
> A picture is worth a 1000 words, don't you think? ☺
>
> http://es.youtube.com/watch?v=RViiUlWty8M
>
> Best wishes, Norma

This is a clear example of an instrumentalization process in which the teacher introduces an innovation in the resources. The teacher uses a link to a YouTube video as a tool to communicate a mathematical idea to one of her colleagues. Even though ourselves (the teachers educators) had previously used this website to post messages on video, this was the first time we saw a teacher using this site as a mean to communicate mathematical ideas.

Example 2, an instrumentation process. After analyzing the asynchronous discussions that teachers produced on the stages 3 and 4 of the orchestration, it became clear that only a few of them highlighted the pragmatic value of the instrumented techniques. In other words, teachers conceived the software as a tool that facilitates the implementation and verification of algorithms, but not as a tool that can serve as a mean to produce mathematical knowledge. Such positions can be illustrated by some of the comments made by the teachers. For example, during the third stage, when the sub-teams had to be defined, one teacher commented:

> *Topic*: Re: General discussion space
> *From*: Sandra
> *Date*: Monday, 24th of November 2008, 15:44
>
> Hello colleagues. We have to define the sub-groups to solve the activity 3.
>
> If you ask for my opinion, I would like to work with paper and pencil. Who else would like to join me? I will wait for your answers
>
> Best wishes to all, Sandra

Then one of the teachers reacted to Norma's comment:

> *Topic*: Re: General discussion space
> *From*: Federico

Date: Monday, 24th of November 2008, 19:35

Hello Sandra.

Hi Sandra, even though I support the use of calculators, I am convinced that the proper use of calculators requires prior understanding about how the things are done. I would like to team up with you, if you agree we could do it. I am open and willing to see other colleagues' points of view.

Best wishes, Federico

My interpretation of the phrase "I am convinced that the proper use of calculators requires prior understanding about how the things are done" is that this teacher perceives technology (in this case, calculators) as an element whose use in the classroom should be subsequent to the work with pencil and paper. This teacher does not perceive the instrumented techniques as a mean to produce knowledge. This idea or position is interpreted here as a component of the operational invariants that this teacher associate with the use of technology to teach mathematics.

For the teacher educators who were observing the teachers' discussions, it was clear that after the teachers had passed through the initial stages of the orchestration, most of them only highlighted the value of pragmatic techniques implemented without mentioning any epistemic value. This issue was explicitly addressed during a meeting that teacher educators held three days after the fourth stage of the orchestration started. This meeting was supported by the use of the software *Skype*. In this meeting we decided that during the fifth stage in the orchestration, where we should discuss with the teachers the work of Lagrange (2005), we will focus the discussion of the concepts pragmatic and epistemic values. In some cases the discussion was very productive. For example, the teacher who was quoted above, mentioned:

Topic: Re: What technology in the mathematics classroom?
From: Federico
Date: Saturday, 13th of December 2008, 04:16

Hello colleagues

Before reading the article of Lagrange I just gave one application, using the terminology of the article, pragmatic. I felt that without a prior knowledge, the use of tools as CAS and/or calculators do not help to generate learning, I mean, I was in favor of using these tools, but apparently I was just giving them a pragmatic value. On integral calculus I promoted the use of tools for the calculations and at the most in the derivative calculations. On differential equations I promoted its use to carry out integrals and so on. So I am very surprised that the article highlights the aspect of the epistemic application. In a sense he was right, because the epistemic application obviously requires a planning and construction of new activities that do not arise naturally from the teaching based on pencil and paper. I would like to finish this comment, leaving the thought and concern of how should be a methodology for applying the epistemic value.

Best wishes, Federico

I interpret this comment as evidence that there has been a change in the operational invariants that the teacher associated with the use of technology, a change that seems to have been motivated by some elements of the set of resources that the teacher interacted with, particularly the concepts of value epistemic and pragmatic value of a technique presented in the article by Lagrange (2005).

Final comments

As I mentioned before a DO is regulated and evolves through the information that the instrumentalization and instrumentation processes provide. However, the type of information that the designer gets about his orchestration, is different for each of these processes. The instrumentalization processes help us to identify the resources that are appropriated, modified or introduced by the teachers. This allows us to see the consequences of these changes and to take them into consideration for improving future orchestrations. In the first example a teacher uses a YouTube video as a mean to communicate mathematical ideas. This particular way of using this type of videos was new even for us the teacher educators. This has been a trigger that has made us reflect on the different uses and functions that could have such resources in future orchestrations.

The information provided by the instrumentation processes is less general. The presence or absence of these processes reveals whether or not the primary and secondary objectives of the orchestration are being achieved. This information allows us to make adjustments and specific modifications to the stages and exploitation modes of the DO with the intention of improving it. The example 2 illustrates this process.

An important idea that has remained implicit in the paper is the iterative or cyclical nature of a DO. Here I am claiming that as the documentacional genesis, an DO can be seen as a process in which an orchestration is applied and its application produces (or does not produces) certain instrumentalization and instrumentation processes, then, taking into account these processes, the orchestration can be redesigned or transformed into a new orchestration. This cyclical nature of the design of tasks in teacher education has been mentioned by other teacher educators (see for example Yackel, Underwood & Elias, 2007; Liljedahl, Chernoff & Zazkis, 2007). One of the main contributions offered by the concept of DO to this discussion is the proposal to focus our attention to the processes may arise during the implementation of an orchestration, and use them as a source of information that can serve as guide for adjusting the original design.

NOTES

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2. An extended and different version of this paper has been submitted for evaluation to the journal *Recherches en Didactique des Mathématiques*. This new version of the paper, which has been written in spanish, includes fresh empirical data regarding the instrumentation and instrumentalization processes.

3. More information about this educational program can be found in www.matedu.cicata.ipn.mx (in Spanish).

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STRUCTURING DISCURSIVE TRAJECTORIES: PROVISIONAL THOUGHTS ON DESIGNING FOR CRITICAL DISCUSSIONS AND SOCIO-SCIENTIFIC DECISION-MAKING*

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This paper constructs an a priori foundation for the educational design of teaching activities that engage students in critical discussions that aim for socio-scientific decision-making. A theoretical exposition of the concepts 'discussion', 'argumentation' and 'decision-making' reveals that we can understand discussion activities that aim at decision-making on some problem issue as possible objects for the implementation of a well established design approach from mathematics education; an approach originally intended for the design of modeling activities.

INTRODUCTION

For nearly two decades increasing attention has been given to student argumentation in the science education community (Driver, Newton, & Osborne, 2000; Jiménez-Aleixandre & Erduran, 2008). Recently, there have been some indications of a shift in focus from students' reasoning - i.e. constructions of singular argumentative moves - to the more dialogic articulation of moves within critical discussions - i.e. the process of producing argumentative moves in discussion contexts (Kuhn & Udell, 2003; Clark & Sampson, 2008). To my mind, such a shift is very welcome; but it also presents us with a challenge: though some considerations have been made on how to *design* for argumentation (Jiménez-Aleixandre, 2008), and though there has been done some work on interaction design to stimulate computer mediated discussions (Ravenscroft & McAlister, 2006), we need to consider in very fundamental terms what it means to take a didactical design approach to argumentative *discussion* activities.

In this paper, I provide an *a priori* groundwork for designing learning activities that engage students in a critical discussion process with the explicit aim of socio-scientific decision-making. My purpose here is *not* to provide a more or less concrete design approach for specific subjects or problem issues. My intention is, rather, to theoretically vindicate that a specific design approach known as "study & research courses" (SRC), which belongs to the *anthropological theory of didactics* (ATD) (Chevallard, 2006; 1992), could in principle be applied on decision-making activities that centre on critical discussions. After portraying the main principles and motifs behind the SRC approach to modeling activities, I argue that the theoretical notion of

* I wish to express my gratitude to the anonymous reviewer of the initial version of this paper for constructive critical remarks and valuable suggestions for modifications regarding both form and content.

decision-making processes allows us to understand such processes as modeling processes, and thus that they are activities which we can design using SRC. I then argue that *if* we abandon an understanding of critical discussions as a series of individual argumentative moves, and, rather, adopt an understanding of such discussions as being dialectical processes that are teleologically guided by a principle of resolving a difference of opinion, *then* we have available an understanding of the relevant discursive *trajectories* in discussions as being both drawn and directed in a fashion similar to the learning trajectories in the SRC approach.

Before I begin to construct this argument, though, I want to briefly flesh out the concept of a 'trajectory'[1]. As will be clear this concept plays a predominant role as the object of concern in this paper. In much educational literature, a (hypothetical) 'trajectory' is often meant "to refer to the teacher's prediction as to the path by which learning might proceed" (Simon, 1995, p. 135) and the requisite content of such a trajectory can be parsed as "the learning goal that defines the direction, the learning activities, and the hypothetical learning process - a prediction of how the students' thinking and understanding will evolve in the context of the learning activities" (*Op cit.*, p. 136). In this context, however, I shall use 'trajectory' in a slightly more generic fashion: instead of reserving the term to denote only the learning path of a student in a specific context, I intend to use it as a way of also making reference to *other kinds* of paths (besides learning) which the student, the actions of the student, or even groups of students, can travel along in an educational setting. More concretely I have in mind making reference to the evolution, and prediction hereof, of the discursive interaction in a group of students. The concept behind the term trajectory is for my purposes very useful. We are dealing with a hypothetical line, which connects two states A (origin) and B (goal), and which in doing so passes through a number of intermediary states. The particular usefulness of that picture is that we can analyze it both as a line, in which case we accentuate the *process* which a (group of) student(s) undergo from A to B, and as a discrete series of *states*. This double force allows us to analyze intermediary states in terms of the overall process and vice versa.

ATD AND DESIGNING TRAJECTORIES

At the heart of the *anthropological theory of didactics* we find the notion of *praxeology* - i.e. the notion that we "can analyze any human doing into two main, interrelated components: *praxis*, i.e. the practical part, on the one hand, and *logos*, on the other hand" (Chevallard, 2006, p. 23). From the perspective of ATD, every human activity, such as conducting experiments in the lab, proving a theorem, or

[1] The idea that designing trajectories could be the primary object of educational design science, was first introduced to me by Carl Winsløw (2009).

even riding a bike, can be analyzed as an actualization of a praxeology. Taking his lead from this outlook of the ecology of knowledge, Chevallard argues that praxeologies are *intersubjectively shared* by, and *idiosyncratic* to, groupings such as social classes, local communities, school classes and research communities etc. (Chevallard, 1991; Tiberghien, 2008). For Chevallard, this means, on the one hand, that such groupings *construct* the group-specific knowledge and epistemic capacities they share, and, on the other hand, that any communication or transference of praxeologies from one group to another in the first instance requires that the given body of knowledge is *transposed* (Chevallard, 1985; Bosch, Chevallard, & Gascón, 2005). In the context of science and mathematics education this has the immediate consequence that any particular body of knowledge, which is produced through an actualization of a particular praxeology, by the scientific or mathematics community must undergo a *didactic transposition* by the teacher and the institutional surroundings (e.g. the curriculum) so as to be taught in class.

The *sine qua non* of a praxeology is its function of solving problems: we invoke a specific praxeology to solve specific problems, like when John thinks to himself 'how am I to transport myself to campus today' is a problem, which John could solve by riding his bike, thereby actualizing the praxeology familiar to him of riding a bike; similarly with the problem of establishing which commercial soap is the better soap. In general: when facing a problem, humans apply specific *techniques* to circumvent it; and praxeology is a useful way of parsing this conduct, because it is not merely a praxis, but a rational conduct in the sense that it, upon inquiry, can be drawn into question and justified (Chevallard, 2006). On this view, the key phenomenon in education is that students are introduced to new and more demanding praxeologies by being posed problems *specifically designed* for the educational context.

In this light, the primary task of educational design becomes one of transposing relevant bodies of knowledge in such a way as to afford meaningful and sensible *trajectories* of situations in which the students can acquire increasingly more complex praxeologies. And in the case of socio-scientific activities involving critical discussions parts of the relevant bodies of knowledge that need to be transposed would be the knowledge and practices of the scientific communities as well as the available knowledge and practices of societal debates involving a connection to science content (Tiberghien, 2008).

It may be possible to argue that a fundamental challenge faces any attempt to describe the phenomena of educational situation in terms of concepts such as transposition or reconstruction. If bodies of knowledge and relevant practices are being *represented to* students how will these students acquire the defining traits of critical citizenry? In the context of the theme of this paper the problem can be restated as one of securing that activities of critical discussions not just mean that students re-apply established knowledge and values that has been transposed to them, but negotiate and independently construct personal criteria for making the sought for decision.

Chevallard, of course, is quite aware of such problems, and gives an elaborate account of how ATD facilitates activities in which students are "finding things *out*" instead of merely finding things by visiting the "monuments" into which the didactic transposition has turned bodies of knowledge (Chevallard, 2006, p. 29).

To this end Chevallard envisages a generic type of teaching situations which he labels "study & research course" (SRC) - where 'research' is meant to explicate the modus of student participation, and where 'course' is in the sense similar to that of a golf course - a course which is "determined essentially by the will to bring an answer, *A*, to some *generating question*, *Q*" (Chevallard, 2006, p. 28). For Chevallard this course is akin to an "institutional *adventure*" (*ibid*); and the didactical design approach in SRC is accordingly to articulate a generating question for a given subject area and foresee, through *a priori* analysis, a hypothetical trajectory of this adventure. Barquero, Bosch, and Gascón (2007) offer a detailed explication of the nature and purpose of SRC in terms of conceptualizing how to structure the trajectories of invoked and articulated praxeologies in mathematical modeling activities: the central idea of SRC is that we are dealing with an activity that involves

> […] the study of a question *Q*, of real interest to the students ("alive"), and strong enough to generate many other questions. The study of *Q* and the subsequent questions it generates lead to the construction of a large body of knowledge […] The sequence (or "tree") of questions generated by an initial question *Q* is, in fact, a sequence of pairs questions/answers: (Q_i,R_i) (Barquero, Bosch, Gascón, 2007, p. 2052).

In this way, the study & research programme allows students to research a given problem that, on the one hand, generates a series of increasingly more difficult and complex sub-problems, and on the other hand, itself can only be comprehensively solved through the interaction with its sub-problems - i.e. the process of solving the generative problem is scaffolded by the sub-problems it itself generates. And, though the main task of the didactic transposition consists in making the relevant body of knowledge explicit as being that which answers a series of questions, the fundamental aim of this approach is that it affords a type of activity in which the modeling activity itself becomes the "study object" (Barquero, Bosch, Gascón, 2007, p. 2059) and thus that the students are not re-applying established knowledge that has been transposed to them, but negotiate and independently construct models. Notice the normative indication in the quote above: not any question can serve the purpose of being a generative question. To my mind, we can, based on this, give a gloss on this in the following way: appropriate generative questions have the feature of being *rich* and *forceful* - rich in the sense of entailing *a priori* a series of sub-questions/answers that call for increasingly complex models, and forceful in the sense of being able to really guide the students through the trajectory of that series of situational models.

To summarize, the primary insight that we draw from ATD/SRC in this context is the idea that the appropriateness of the design of an educational modeling activity depends on the appropriateness of the chosen generative question in terms of how well that question is able to generate a series of sub-questions/answers and thus *teleologically* guide students through a foreseen modeling trajectory. And it is this insight and its individual constituents that I will try to superimpose onto a theoretical model of critical discussions and decision-making processes in the following.

CRITICAL CITIZENSHIP AND DECISION-MAKING

It is increasingly clear that we have to regard teaching for scientific literacy as involving the preparation of students for a kind of citizenship, which can be characterized as broadly critical (see e.g. Aikenhead, 2005; Kolstø, 2001). Parsing the role of science teaching in terms of preparation for critical citizenship led, primarily in the Anglo-Saxon parts of the world, to the concept of “Socio-Scientific Issues” (see e.g. Ratcliffe, 1997, Sadler et al., 2004) which can be best characterized as activities in which students negotiate and decide upon problem issues that have a political/ethical nature and are conceptually related to some more or less specific science content.

In what has become one of the most influential works on students’ decision-making in science teaching, Kortland argues that the generic model for decision-making in many teaching contexts seems to be a “normative model” that looks “like a stepwise procedure of identifying the problem, developing criteria, generating alternatives, evaluating alternatives, and finally choosing and implementing the best solution” (Kortland, 2001, p. 36). According to Menthe (2006) such models are not only unrealistic in displaying the decision-making process of real persons; they are also too simplistic to be useful in school contexts, he argues. Menthe consequently reconstructs decision-making as a competence, and by involving action theory he proposes a concept of decision-making, according to which making a decision involves a “situational analysis, which is the *picture* or, in other words, the *map*, which the student constructs” (Menthe, 2006, p. 33, my translation and emphasis). It is not coincidence that this description dovetails with representational terms (picture, map): an informed decision-making process involves constructing a “*model of the situation*”, which involves a range of “alternative actions” to be taken in the situation, and when the decision is made one of these alternatives are chosen under the guidance of a specific set of negotiable quasi-personal criteria (*ibid*, my translation and emphasis).

The prospects of conceptualizing decision-making as essentially being a (inter)personal *modeling* process is of importance for the groundwork to be laid in this paper. For if we can understand decision-making processes as modeling processes it is to expect that we can take a SRC approach in the design phase and begin to make explicit which trajectories we foresee the students to follow. In other words: the SRC approach helps us to make explicit *that* it is appropriate to be mindful of the specific trajectories of the series of situational models the students construct trying to decide on a specific problem issue. And it is clear that the 'specific problem issue', I allude to here, is that which would correspond to the generative question in an SRC. I turn now to connect the notion of a generative question with the notion of a problem issues as both creating and structuring a critical discussion.

FROM ARGUMENTS TO CRITICAL DISCUSSIONS

At least two reasons can be given for the centrality of the concept of argumentation in education research. First, being a critical citizen involves (among other things) to be epistemically empowered, which, in turn, means to be able to navigate a field of reason-giving practice (Sellars, 1963). Second, from the perspective of certain theories of learning, activities in which students construct arguments can be beneficial for the learning of those students - the construction of arguments epitomizes, for instance, the externalization of inner episodes, which is so central for learning on Vygotsky's account (1978). Until recently, the majority of approaches to argumentation in the science education community have so far belonged to what I want to call the *Toulminian paradigm*. The basic tenets of this paradigm include not only a specific fashion of analyzing argumentation, but also a specific way of understanding what argumentation is. Toulmin's model of argument patterns (Toulmin, 1958) is a tool for analyzing argumentation on account of the structural coherence between claims and their justifications: an argument is valid if the claim involved is endowed with epistemic authority though the citation of data, warrants, backings and qualifiers. To some extent, this model was *the* inspirational framework behind the analysis of argumentation in the first decades of argumentation study in science education. Thus many of the models that have been applied in science education research are *explicitly* derived from Toulmin's original model (see e.g. Osborne, Erduran & Simon, 2004; Zohar & Nemet, 2002; Zeidler & Sadler, 2008). But, beyond being merely a collective application of similar analytical models, the *Toulminian paradigm* manifests an understanding of arguments as linguistic arrays of statements that should be analyzed in terms of how, and with what success, their internal structure allows the transfer of epistemic authority from that which justifies to that which must be justified. To be sure, the fact alone that argumentation, in the *Toulminian paradigm*, is viewed as something that can be analyzed without remainder in terms of its internal structure is not criticizable. But this rendition of argumentation is limiting the paradigm to consider only a specific trope of linguistic activities. Indeed, numerous critics - both within science education and argumentation theory - point to the shortcomings of Toulmin's model when we want to analyse argumentative *discourse* between two or more persons - in the *Toulminian paradigm* argumentation can solely be analyzed as being a monological affair (Van Eemeren, Grootendorst & Kruiger, 1987; Duschl, 2008).

At this point it may be beneficial to remind ourselves of a well-known distinction between singular argumentative moves, considered as the end *product* of a chain of (inner) episodes of reasoning, and argumentative discourse, considered as the social and dialogic *process* of articulating reasons in a critical discussion (see e.g. Kuhn & Udell, 2003; Van Eemeren & Grootendorst, 2004). To my mind, this distinction is as illustrative as it is dangerous. It is illustrative because it allows us to better understand what is meant with 'argumentation' within a given theoretical framework: in the *Toulminian paradigm*, for instance, argumentation is necessarily arguments as products, for, I would argue, no real meaning can be given to the process of articulating reasons. But the distinction is also dangerous, because it at times is introduced as a distinction *in re* (see e.g. Jiménez-Aleixandre & Erduran, 2008); as if we can meaningfully talk about both senses of argumentation within one framework; and this, I think, is problematic. Again taking the *Toulminian paradigm* as an example, if we accept to study argumentation along such lines we are always already bound to analyze argumentative discourse *as if* it is consist of a series of singular argumentative moves.

As announced above, I want to focus on critical discussions, or, rather, on argumentative discourse as situated in a dialogic process in which two or more parties resolve a difference of opinion and make a socio-scientific decision. One theoretical framework that allows such a focus is the *pragma-dialectical* theory of argumentation (see esp. Van Eemeren & Grootendorst 1982; 2004). In the first instance, it can be characterized in contrast to the *Toulminian paradigm*: the pragma-dialectician understands and analyses arguments *as if* they were complexes of speech acts that play a role in a critical discussion (Van Eemeren & Grootendorst, 2004). This, of course, does not mean that the pragma-dialectician can only analyze dialogue and not monological texts or assertions, it merely means that monologue is *reconstructed* as playing a role in a critical discussion. Argumentative moves, on this account, should be analyzed, in terms of what their function is in social activities of resolving a difference of opinion. Here a structural analysis akin to Toulmin's model can be a helpful tool to get a glimpse of the layout of these moves; but apart from focusing on the argumentation structure the pragma-dialectical focuses on making explicit the standpoints and the commitments of the parties, the position of the parties in the beginning, during, and at the end of the discussion, the arguments adduced during the discussion, and the argumentation schemes that the parties put to use (Van Eemeren, Grootendorst, & Snoeck Henkemans, 1996).

The pragma-dialectical theory explicitly aims at being a descriptive as well as a normative framework for understanding argumentation. Here, the study of argumentation becomes describing the manifested argumentative discourse against the backdrop of a theoretically *ideal model* of the structural dynamics of critical discussions, which projects a normative "procedure for how speech acts should be presented in order to be constructive moves in such a discussion" (Van Eemeren & Grootendorst, 2004, p. 20). In a nutshell: the ideal includes the normative criteria for acceptable linguistic behavior in critical discussions. Beyond this, the model has a feature, which for our purposes is of interest, namely that it as such stipulates how ideal critical discussions follow a specific trajectory over four different *stages* in which the individual speech acts have different *functions*:

Confrontation: where "it becomes clear that there is a standpoint that is not accepted" (Van Eemeren & Grootendorst, 2004, p. 61).

Opening: where "the parties to the difference of opinion try to find out how much relevant common ground they share"(*ibid*).

Argumentation: where the "protagonists advance their arguments for their standpoints that are intended to systematically overcome the antagonist's doubts or to refute the critical reactions by the antagonist" (*ibid*).

Conclusion: where "the parties establish what the result is of an attempt to resolve a difference of opinion" (*ibid*).

In practice many of the parts of each stage remain implicit, but without some explicit parts of the argumentation stage and at least a presumed difference of opinion we are not dealing with a critical discussion. Further, discussions in practice seldom abide by the temporal succession presented here (but a reconstruction of such discussions will attempt to structure and organize the parts as belonging to either one of the four stages.) Notice that in connection to the theoretical model of decision-making described above, we would expect that students would pass through *multiple* cycles of the four stages, and in that sense multiple discussions - namely, (at least) one for each situational model constructed in the decision-making process.

We should, I think, let this theoretical apparatus behind the concept of a critical discussion guide us in attempts to design teaching activities that focus of critical discussions towards socio-scientific decision-making. To recall, this decision-making process was revealed to be analyzable (in principle, at least) as an interpersonal modeling process. From my perspective we can take with us at least two fundamental insights. First, since critical discussions in this approach always already aim towards resolving a difference of opinion the very act of placing student groups in a situation where they need to make a socio-scientific decision on a problem issue is it self a way of structuring a critical discussion. Here we see a clear connection to ATD/SRC: the very act of introducing a suitable generative question goes a long way in the direction of structuring modeling activities. Second, it could be beneficial to facilitate and secure that the students, considered as parties, cover each stage in their discussion. And this includes the partial envisioning of the *trajectory* of a specific future discussion on a specific problem issue. Designing for constructive critical discussions in this light becomes scaffolding the discursive trajectories of students' argumentative discourse so that this discourse includes speech acts that are appropriately fitted into the different discussion stages and play constructive roles in the process of resolving a difference of opinion. Once again an important bridge can be build to ATD/SRC. Being aware of the learning trajectories of the student is key in the design process: for the pragma-dialectician the notion of resolving a difference of opinion is the normative regulatory ideal - much akin to linguistic rules in general - that *tacitly* structures the interlocutors' conduct in critical discussion. Similar to how the generating question projects a trajectory through a subject area - this regulatory ideal projects a trajectory through a discursive field. In both cases the conduct of the involved persons is teleologically guided by an aim. In light of this, designing for critical discussions towards decision-making becomes, *prima facie*, to articulate a specific problem issue to which there could be a difference of opinion and which is able to support a specific trajectory which abides by the theoretical structure of "ideal" critical discussions.

CONCLUDING REMARKS

In this paper I have argued that there is, on the conceptual level, a structural agreement between ATD/SRC and theoretical models of decision-making processes and critical discussions. The key point is that not only are decision-making process (*qua* their modeling nature) possible to design from a SRC perspective, critical discussions are processes in which the discursive practices of the discussants are teleologically guided by a regulatory ideal in a way much similar to how the ATD/SRC framework envisions that generative questions can guide the learning trajectories of students. In the first instance this puts an emphasis on the importance of the problem issue in the design of such activities. And although this is not novel information, the ATD/SRC framework can help us make explicit exactly what it means to transpose appropriate problem issues into the classroom context: namely, that appropriate problem issues have the feature of what I have be calling *rich* and *forceful* - i.e. able both to generate a series of connected sub-problems and to teleologically guide the students through modeling processes that lets them decide on these problems through articulating the situational models in argumentative discourse.

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THE GENERATIVE QUESTION AS A TOOL FOR CONTENT DEVELOPMENT FOR A MUSEUM EXHIBIT

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Recently, research on science education in formal settings has seen an increased interest in didactics as a design tool. A corresponding shift has not taken place in research on science education in informal contexts. The present paper applies didactics to the design of an informal learning environment: a museum exhibit. The generative question is put forward as a candidate for guiding a theoretical re-engineering of an existing exhibit Cave Expedition*. The criteria for using the generative question in the design of a museum exhibit are outlined in general terms, and a specific candidate for a generative question is put forth. The implications of this generative question for the theoretical re-design of the existing exhibit are discussed.*

INTRODUCTION

There is a growing realisation in the Anglophone science education research literature that general pedagogical recommendations and guidelines are insufficient when it comes to designing formal teaching interventions about a given science topic (Andersson & Wallin, 2006; Lijnse, 2000). Accordingly, research has in recent years reflected an increasing interest in the development of content-specific knowledge regarding the teaching of science subjects (Janssen et al., 2008; Scott et al., 2006) as well as tools to develop such content-specific knowledge (e.g. Buty et al., 2004; Andersson & Bach, 2005). However, the research on designing informal teaching interventions such as museum exhibits has not seen a corresponding shift in focus, and largely continues to contribute to the accumulation of general recommendations and guidelines designated here as museum pedagogy. A shift in focus from museum *pedagogy* to museum *didactics* is needed.

Didactics is defined as the scientific study of the actions taken to cause the diffusion of a certain body of knowledge in a certain institution, and includes the knowledge resulting from such study (Chevallard, 2007). As suggested by this definition, didactics has a strong design component which involves implementing insights gained from research in order to achieve improved practice (Artigue, 2009). In the following, a didactic design tool: the generative question (Chevallard, 2007) is applied to a case of informal biology educational design, namely the engineering [1] of a museum exhibit. This study will thus theoretically answer the following research question: to which extent does application of the generative question as a tool for knowledge development provide an improved framework for exhibit engineering as gauged against the framework implemented by exhibit designers in a previously reported case of exhibit design (Mortensen, 2009a)?

The intent of this study is to examine the merit of creating and applying a didactic tool in the realm of informal science education. The study deals with a specific case of biological knowledge but the findings may potentially serve as a paradigm case of a larger class of phenomena.

THEORETICAL FRAMEWORK: THE GENERATIVE QUESTION

The generative question is a design tool originating within the Anthropological Theory of Didactics (ATD) which holds that any commonly occurring human activity can be described in the form of a praxeology (Chevallard, 1999). A praxeology is a general model which links the practical dimensions (the *praxis*) and the theoretical dimensions (the *logos*) of any human activity (Barbé et al., 2005), and mastering a praxeology corresponds to mastering the how and why of a body of knowledge.

Recent studies in science and mathematics didactics have shown that the failure of learners to solve problems may be ascribed to a disassociation of the taught tasks and techniques (the *praxis*) with the rationale behind them (their *logos*). In these cases, the use of the generative question as a didactic design tool successfully remedied the problem, i.e. established the connection between *praxis* and *logos* (cf. Rodríguez et al., 2007; Barquero et al., 2007).

Briefly, the generative question is formulated by an education engineer based on an *a priori* analysis of a body of knowledge to be taught. When studied by the learners, this initial question gives rise to a line of inquiry which documents, and thus allows for the retrieval of, the original relationship between problems and theories, or *praxis* and *logos*. The generative question must accordingly be a) strong enough to generate a series of question-answer pairs, b) of real interest to the learners in question, c) devised without resorting to the praxeology which it is meant to create, and d) within the means of the learners (Barquero et al., 2007; Rodríguez et al., 2007).

Applying the theoretical framework to museum exhibit design

To which extent can the body of knowledge which it is the exhibit's purpose to disseminate to the visitor be defined in terms of a praxeology? The notion of praxeology assumes a certain regularity of tasks and the way they are carried out, and the heterogeneity of a museum's exhibits (or tasks) and of its visitors and their approaches to the exhibits (or techniques) makes it difficult to conceive of any sort of regularity of *praxis*. Conversely, the

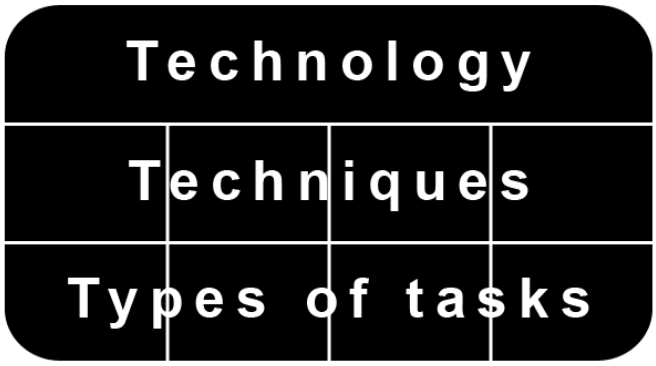

Figure 1: The praxeology of a single museum exhibit may be described by a number of different types of tasks and their corresponding techniques, overarched by a common technology. After Artigue & Winsløw, 2009.

argument could be made that exhibit design should intentionally seek to address and mobilise pre-existing techniques that are familiar to the visitors from other praxeologies (C. Winsløw, pers. comm., March 13, 2009). Exhibit engineering could harness the potential of visitors' prior experience by specifically invoking such commonly occurring techniques.

To which extent is the *logos* aspect of a praxeology present during visitors' interactions with an exhibit? Visitor interactions with museum exhibits range from thoughtful exploration to mindless button-pushing (Paris, 1997), and while the former arguably entails some degree of reflection about the interactions with the exhibit (or technology) such reflection usually remains tacit unless measures are taken to capture it. Further, while carefully designed museum exhibits may in some cases stimulate a certain degree of reflection in the visitor about the presented tasks and the techniques s/he uses to solve those tasks (the technology), it is more difficult to imagine that interactions with a single exhibit can generate any kind of overarching theory in the mind of the visitor. Museum learning is generally considered to be of a long-term cumulative nature (Falk & Dierking, 2000; Paris, 1997), and a praxeology that attempts to model the visitor's experience with and understanding of a single museum exhibit may accordingly be best described by a number of tasks, the corresponding techniques, and a common technology (Figure 1).

In the present paper, the exhibit and its content and teaching strategy are considered to comprise tasks, the visitors' applications of themselves to these tasks are considered techniques and the visitors' rationales for their actions are considered their technologies.

CASE: THE EXHIBIT *CAVE EXPEDITION*

The science centre exhibit *Cave Expedition* exemplifies the argument presented in this paper. *Cave Expedition* is one of four exhibits which comprise the thematic cluster Darkness in the exhibition *Xtremes* [2]. *Xtremes* is an exhibition on animal adaptations to extreme environments and consists of five clusters. In addition to Darkness, the exhibition features the clusters Heat, Cold, Aridity, and Low oxygen.

The biological content presented in *Cave Expedition* is *the adaptations of the blind cave beetle to its environment of permanently dark caves*, and the objective of the exhibit is to enable the visitor to experience how the cave beetle is adapted to its environment (Executive Committee, 2005). The means by which this experience is sought mediated is an immersion exhibit, defined by the creation of an illusion of time and place through the reconstruction of key characteristics of a reference world and by integrating the visitor in this reconstructed world (Bitgood, 1990). The main component of the exhibit *Cave Expedition* is thus an artificial cave which represents a scale model of the cave beetle's habitat which visitors can navigate through playing the role of the cave beetle.

An empirical study showed that although visitors to the exhibit went through the *praxis* intended by the exhibit engineers, the *logos* they constructed on the basis of this *praxis* was not what was intended (Mortensen, 2009b). Rather than perceiving the exhibit to be about cave beetles, the visitors interpreted *Cave Expedition* from an anthropocentric point of view as exemplified by the following statements made by three different respondents:

> This experience just shows you other senses [than vision] that you can rely on when you are in a different situation.
>
> It's supposed be a representation of what it's like to live in a cave where no light penetrates.
>
> The usual life of a blind [person].

The exhibit *Cave Expedition* thus represents a case not of disassociation between *praxis* and *logos*, but of non-intended association between *praxis* and *logos* by the learners, and consequently constitutes a candidate for the formulation and implementation of the generative question framework.

SYNTHESIS

The body of knowledge which was the point of departure for the exhibit *Cave Expedition* originated in the scientific literature and may be summed up as: the characteristics of the cave beetle's environment, the characteristics of the cave beetle, and the interactions between them (Figure 2). This body of knowledge serves as the point of departure for the development of the theoretical exhibit *Cave Expedition II* as well. It should not be understood as the learning objective of the theoretical exhibit; rather, it is the basis on which the generative question is formulated and serves as the background knowledge on which a conjectured trajectory of question-answer pairs may draw.

The generative question must be of real interest to the learners in question

The first requirement of the generative question is that it is 'alive' and of genuine interest to the learner – in this case, the museum visitor. One way to cater to the visitor's interest is to make the generative question pertain to them (cf. Rodríguez et al., 2007). The idea of placing the visitor in the role of the cave beetle is thus retained from the design of *Cave Expedition*, but with a strong emphasis on making this role clear to the visitor. Accordingly, the generative question should be framed in these terms.

The generative question must be strong enough to generate a line of inquiry

The initial question must be of a sufficiently high level of abstraction to allow for at least some exploration of the body of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves*. A question pertaining to the cave beetle's daily struggle for survival may generate lines of inquiry regarding sources of food, sources of danger, and how the cave beetle deals with such challenges in its daily life (cf. Figure 2). Shepherdson (2002) found that children's ideas of ecological niche tend to be one-directional, i.e. they think about what an insect eats but not what eats the insect. Such prior conceptions [3] should accordingly be specifically addressed by the generative question and subsequent exhibit design.

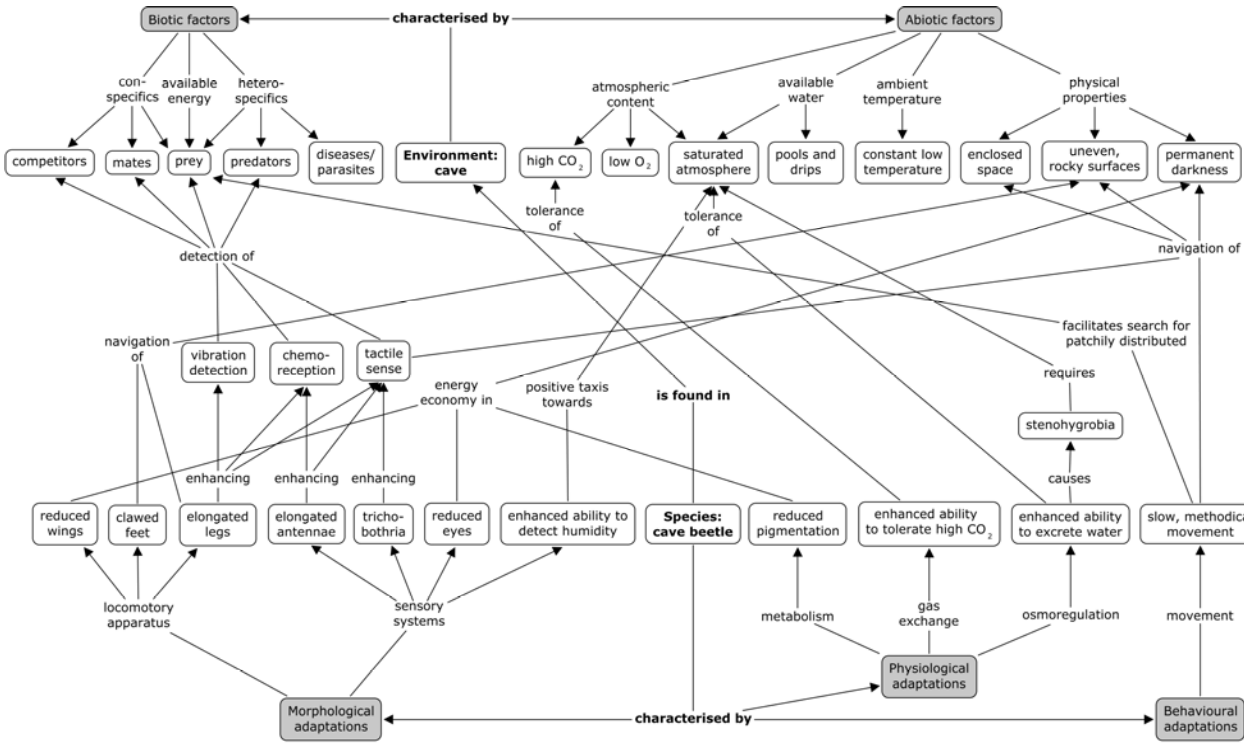

Figure 2. The body of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves* as summarised from scientific primary and secondary literature. Shaded boxes represent categories. From Mortensen (2009a).

The generative question must be devised without resorting to the praxeology which it is meant to create

The generative question must be able to precipitate the desired visitor-exhibit interactions and resulting reflections without informing the visitor beforehand what these interactions and reflections are. Formulating the generative question and the subsequent exhibit engineering to 'mobilise technologies from visitors' other praxeologies' as discussed in the preceding may be a means to achieve such intended visitor interactions. The existing exhibit *Cave Expedition* to some extent already does this; by placing the visitor in a darkened tunnel, the exhibit design harnesses the human technique and corresponding technology of using sense of touch when deprived of sight.

The generative question must be within the means of the learners

The 'means of the learners' may be interpreted to mean commonly held visitor conceptions about insects and insect life which do not conflict which what is to be learned, but which may serve as the basis upon which correct conceptions may be built: 'founder notions' (Buty et al., 2004). For example, research shows that children of ages 5-15 characterise insects as being small and equipped with antennae and legs (Barrow, 2002; Braund, 1998; Shephardson, 2002); such universally held conceptions should be addressed by the generative question and the subsequent exhibit engineering.

THE GENERATIVE QUESTION

A suggestion for a generative question based on the preceding discussion could be: **Can you last a day as a cave beetle?** This question, stated boldly at the entrance to the exhibit, would unequivocally place the visitor in the role of the cave beetle. The idea of the exhibit as a scale model of the cave beetle's habitat is retained from the existing exhibit *Cave Expedition*; however, cues to the scale could be given in the form of a 1:350 scale model of a cave beetle on the outside cave wall. This would render the cave beetle model and the human visitor the same size, and drawing on children's (and presumably adults') conception of insects as being small, the model would serve to establish the exhibit as a representation of a scaled-up world.

The generative question **Can you last a day as a cave beetle?** placed prominently at the entrance to the cave would indicate to the visitor that the question can be answered by entering the exhibit – the cave beetle's habitat. Even though children (and presumably adults) do not conceive of insects as cave dwellers (Barrow, 2002; Shephardson, 2002), the term '*cave* beetle' as well as the prominent location of the beetle model on the outside of the cave will serve as cues to this effect. A visitor line of inquiry about the characteristics of the cave habitat could be supported by the design of the artificial cave, both inside and out, to reflect those characteristics of the cave beetle's habitat that signify 'cave' to human beings. Some of these characteristics are present in the existing exhibit *Cave Expedition*, for example uneven rocklike walls and darkness; others, such as the sound of dripping water could, if included in *Cave Expedition II*, help strengthen visitors' perception of the exhibit as a cave (cf. Bitgood, 1990) while remaining true to the scientific body of knowledge which the exhibit is based on (Figure 2).

The generative question **Can you last a day as a cave beetle?** would provide the visitor with a challenge in terms of the daily struggle for life. While they are perhaps not conscious of the cave beetle's role as both predator/consumer and prey, children are able to reason based on perceivable features of a phenomenon (Driver et al., 1985). Equipping the cave exhibit with correctly scaled, easily discernable models of both food items (for example, cricket eggs) and predators (for example, cave spiders) could scaffold a visitor's line of inquiry by precipitating reflections on the different roles of these objects in the cave beetle's daily life.

Finally, the engineering of the exhibit *Cave Expedition II* described in the preceding precipitates the use of those human senses that are analogous to the senses a cave beetle must rely on: tactile sense and to some extent hearing. In this way, *Cave Expedition II* (as the original *Cave Expedition*) makes use of the common human technique of recruiting alternative sensory modalities when their sense of vision is impeded. Thus, even though the *adaptations of the cave beetle* are not explicitly present in the generative question suggested here, the question is still capable of creating an experience of them. The praxeology suggested by the generative question **Can you last a day as a cave beetle?** and the resulting theoretical engineering of *Cave Expedition II* is exemplified in Table 1.

Task	Recognise intended visitor role as cave beetle	Perceive scale of the environment represented by exhibit	Recognise exhibit as representation of cave	Recognise models as parts of cave beetle's feeding ecology
Task embodied by	Headline over entrance to cave ('Can you last a day as a cave beetle')	1:350 model of cave beetle on outside of cave	Uneven rocklike walls of cave, enclosed space inside cave, sound of dripping water	Scale models of cricket eggs and spiders
Technique	Read text and acknowledge assigned role or challenge	Recognise model of cave beetle as insect and extrapolate exhibit scale	Identify external and internal characteristics of exhibit as 'cave-like'	Feel models of eggs and spiders; discern difference; reason the different roles of the items
Technology	Experience vicariously and understand that the cave beetle's habitat is characterised by being dark, rocky, wet, and enclosed; that the beetle navigates using touch and hearing, not vision; that there are other organisms in the cave beetle's habitat and that the cave beetle must use touch to discern these in order to survive.			

Table 1: Examples of the tasks, techniques, and technology that form the projected praxeology of the exhibit *Cave Expedition II*.

DISCUSSION

The scope of this paper does not allow for a thorough analysis of the body of knowledge *the adaptations of the blind cave beetle to its environment of permanently dark caves*, nor for an in-depth synthesis of a theoretical exhibit design based on the suggested generative question. However, it is clear that the application of the generative question framework as a first design iteration of the exhibit *Cave Expedition* was able to generate alternative ideas for exhibit engineering.

The generative question framework is a tool for structuring a body of knowledge by anticipating the various trajectories of inquiry the question may precipitate. However, there is a danger in anticipating too closely these trajectories in the design of an exhibit; they have the potential (risk!) of being transposed into what may become 'monuments of knowledge' (Chevallard, 2006) which the museum visitor encounters but does not perceive the significance of. To avoid this 'monumentalisation', a certain degree of freedom must be built into the embodiment of the knowledge in the exhibit: in the words of Chevallard: 'knowledge must sacrifice itself, including its possible subsequent uses, from the moment it no longer appears as something that allows answering certain questions, solving certain problems' (2004).

The design iteration of *Cave Expedition* presented here attempts to reflect the complexity of the body of knowledge in question rather than a series of anticipated trajectories of inquiry represented by a sequence of stations. Accordingly, when the visitor enters the exhibit they are not merely thrown into darkness (which is one aspect of cave beetle reality) they are being thrown into the entire complexity of the cave beetle habitat. The lines of inquiry found through the analysis of the body of knowledge are present, but in the form of possibilities rather than installed stations.

The success of an immersion exhibit as a teaching strategy of a body of knowledge relies on three basic principles: the presentation of the exhibit as a coherent whole with all objects supporting the representation, the integration of the visitor as a component of the exhibit, and the consequent dramatisation of matter and message (Belaën, 2003). The generative question **Can you last a day as a cave beetle?** arguably situates the visitor in their role as a cave beetle, sets the stage for the subsequent interaction by creating a correctly scaled yet recognisable representation of a cave beetle habitat, and suggests a course of action for the visitor by challenging them to step into the reconstructed cave beetle habitat and explore the challenges facing a cave beetle in its everyday life. Consequently, the theoretical engineering of *Cave Expedition II* addresses some of the shortcomings of the original *Cave Expedition*.

NOTES

1. Exhibit engineering: the process of originating, developing, and implementing an exhibit (Mortensen, 2009a).

2. The exhibition *Xtremes* was developed in collaboration between the Danish science centre Experimentarium, the Dutch natural history museum Naturalis, and the Royal Belgian Museum of Natural Sciences (RBINS), and has been on display at all three venues. It is presently on display at RBINS, where it will remain until September 2009.

3. No studies of adult's conceptions of insects could be located at the time of writing, and visitors' conceptions of insects and insect life are accordingly modelled on those of children.

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TRANSFERRING ‘THE THEORY OF DIDACTICAL SITUATIONS” FROM MATHEMATICS TO SCIENCE EDUCATION BY THE USE OF OBSERVATIONS

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The theory of didactical situations (TDS) has proven its worth during decades in the French school system. Recently, attempts have been made to transfer this theory from its origin in mathematics education into science education in general. These attempts seem to be successful, but this paper discusses some considerations to take into account when doing so. Herein the paper has distinguished between students' own observations and students' work with others' observations. When working with the students' own observations the epistemological gain might be bigger than otherwise.

INTRODUCTION

One of the main focuses in science and mathematics education in the Danish school system and in the rest of the western world as well is how to get the students more interested in science and mathematics (UVM, 2003, EU, 2004, NSB, 2004). It has been mentioned several times that we need more young people to have a career in science in order to maintain and develop the high living standards of our society. In order to achieve this goal it is necessary to change the forms of teaching in such a way as to make science more interesting for the students. In other words, a report to the Nuffield Foundation concludes:

“The irony of the current situation is that somehow we have managed to transform a school subject which engages nearly all young people in primary schools, and which many would argue is the crowning intellectual achievement of European society, into one which the majority finds alienating by the time they leave school. In such context, to do nothing is not an option” (Osborne & Dillon, 2008, p. 27)

One of the things already done is the teachers’ focus on the usefulness of science for the students. In international studies like the ROSE-study (Relevance of Science Education), students have problems seeing science as relevant to their own life and education (Schreiner & Sjøberg, 2007). Part of this problem might come from the curricula based teaching that the students meet in school. Well-meaning and enthusiastic teachers might "overload" the students with facts and phenomena from science. As Hviid & Krøjgaard says:

“Only the fewest catch the inner logic of the subject areas, whereas the majority have the feeling of being taken on a ride, where others have pointed out the direction and where you get answers to questions that you have not asked yourself, and such

answers are ‘useless’ to you” (Hviid & Krøjgaard, 2005, p. 266, *author's translation from Danish*).

A problem might therefore be that the students do not get to formulate their own questions, thereby their curiosity is ‘killed’ and science education becomes alienating for them. If we are to keep students interested in and curious about science it is therefore important to let the students ask their own questions and find the answers to these questions. It has to be the job of the teacher to put the students into situations in which they encounter problems that invite the students to ask questions about them.

For this purpose the teachers need tools. One of these tools could be the Theory of Didactical Situations (TDS) in Mathematics (Brousseau, 1997). It is outside the limits of this paper to fully account for the whole theory, but instead some details of designing the classroom teaching around this theory will be discussed. Recently, there have also been attempts made to transfer this theory from the didactics of mathematics education into the didactics of science education (eg. Christiansen & Olsen, 2006; Evans & Winsløw, 2007). In this paper some implications of the transition of a theory from mathematics education into science education will be discussed. A key point here is to rely on the students’ ability to do scientific observations in order to transfer the theory between two domains. The paper also suggests using the combination of TDS and students’ scientific observation in order to trigger the students’ affective sides of learning.

THE THEORY OF DIDACTICAL SITUATIONS

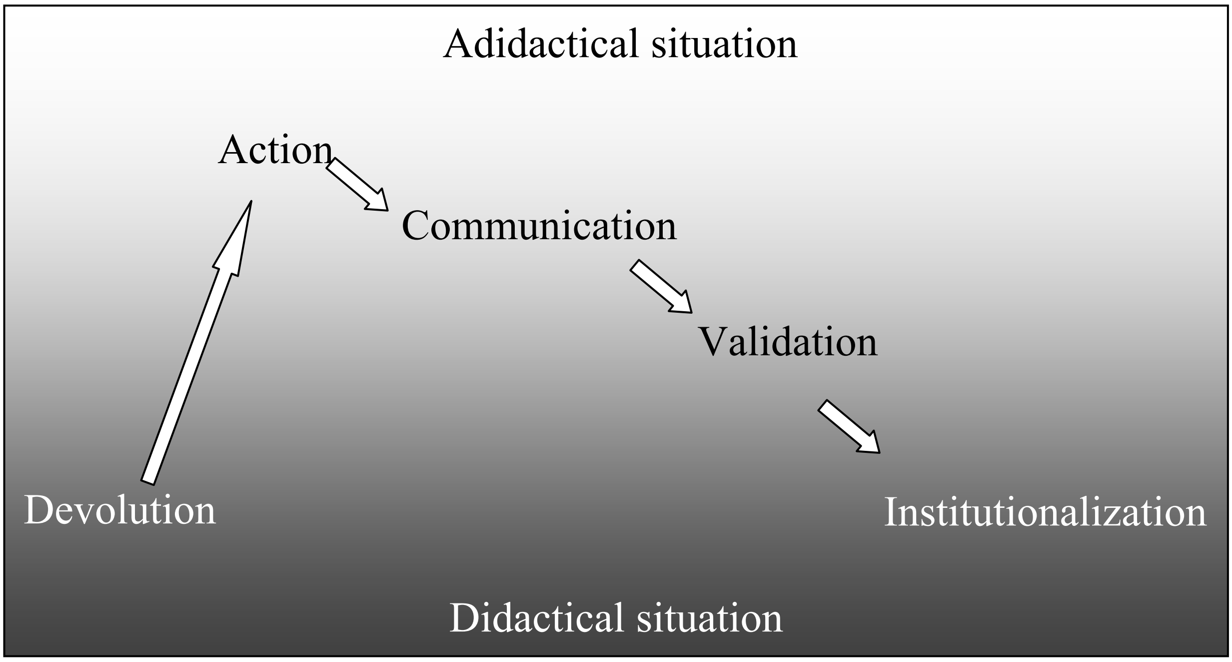
The theory of Didactical Situations (TDS) started in the French mathematical didactical research. The main architect of this theory is Guy Brousseau, who led Centre pour l’Observation de l’Enseignement des Mathematique from 1972 to 1997. Associated with the center there was a school (École Jules Michelet) in which the researcher was able to carry out very advanced teaching observations and was able to do spiraling development of didactical designs (Brousseau 1997). It was in this milieu that TDS evolved and developed. The theory is therefore founded in a huge amount of research in the practical mathematical teaching and not just an outcome of theoretical thinking and has, as such, proven its worth during decades in the French school system.

The TDS has its roots in epistemology rather than psychology or pedagogy (Winsløw, 2006). This means that TDS is concerned with how to evolve essential knowledge in a specific content area. As a theory, TDS therefore only operates with the cognitive side of learning. As mentioned earlier, it is outside the limits of this paper to fully describe the theory, but for further reading the English translation of Brousseau’s original work in French is recommended (Brousseau, 1997). In this paper there will only be described the parts of TDS that are important for the purpose of this paper.

The TDS introduces the term *didactical contract*. This is a two-way imaginary contract between the teacher and the students. The teacher's part of the contract is to create a milieu for the students in which they can learn the subject determined by the teacher. The students' part of the contract is to engage in the session knowing that they are working on gaining knowledge which the teacher already possesses. Within this contract, the work of the teacher is referred to as the *didactical situation* and the work of the students is referred to as the *adidactical situation*. The didactical milieu could be seen as a digital milieu consisting of either didactical or adidactical situations but it might be more appropriate to see it as an analogue milieu ranged between totally didactical situations and totally adidactical situations as illustrated in figure 1[1]. Brousseau (1997) describes the work of the students in adidactical situations like this:

"The student learns by adapting herself to a *milieu* which generates contradictions, difficulties and disequilibria, rather as human society does. This knowledge, the result of the student's adaptation, manifests itself by new responses which provide evidence of learning." (Brousseau, 1997, p. 30)

The students therefore learn this essential knowledge from the specific content area when they are introduced to conflicts with their already existing knowledge. This happens in what TDS calls the *didactical game*. The didactical game referrers to five phases, namely: (i) *devolution* where the teacher hands over the assignment to the student, (ii) the *action phase* where the student is taking up the assignment and making her first individual hypothesis on how she might solve the problem, (iii) the *communication phase* where the student puts her hypothesis into words and explains it to her fellow students or to the teacher, (iv) the *validation phase* where the



hypo-

Figure 1: The didactical contract and its content ranging between the teacher's and the students' work.

thesis is tested to see if it actually is a solution to the problem, and finally (v) the *institutionalization* where the teacher catches up on this newly gained knowledge and puts it into other examples of scientific knowledge where this fundamental knowledge is the basis of understanding.

Devolution is, as illustrated in Figure 1, a didactical situation since it is the job of the teacher to present the milieu in which the students are going to work and then hand over the assignment to the students. In other words, the teacher presents the didactical contract to the students and hands it over to the students in the action phase, where the students then begin their part of the didactical contract in the adidactical situation. While working with the assignment, the students come to formulate hypotheses and validate them according to their findings in the work with the assignment. This happens with more or less help from the teacher as seen in Figure 1. Finally, this essential knowledge is put into perspective at the institutionalization by the teacher in a didactical situation. In the following discussion it will be presented how TDS has been used not only in mathematics education but also how there have been attempts to transfer the ideas of TDS into science education.

CASES FROM MATHEMATICS AND SCIENCE EDUCATION

A classical example of how essential mathematical knowledge can be realized and conceded by the students is a puzzle with a problem of contingency. The problem is designed by Brousseau (1997) and is referred to by e.g. Winsløw (2006) and Evans & Winsløw (2007). Here the students are presented with a puzzle (a quadrate in five pieces) that they must enlarge. The only information the students get is that a side measuring 4 cm in the original must be 7 cm in the new enlarged puzzle. While working with the creation of the new bricks to the larger puzzle, the students realize that it is not a good strategy just to enlarge every side of the bricks by 3 cm, but that every side must be multiplied by a factor of 7/4. According to Brousseau, as mentioned earlier, the students are brought into a situation of disequilibria, and have to find a way (a hypothesis) to regain equilibrium. It is important to take this into consideration when trying to transfer TDS from the didactics of mathematic to the didactics of science. As seen earlier, there have been some attempts to find essential knowledge in science which can be formulated within the frames of TDS (Christiansen & Olsen, 2006 and Evans & Winsløw, 2007).

In an article by Christiansen & Olsen (2006), pharmaceutics are put into the frames of TDS. Here is an example of how a problem can be formulated to fit into TDS. The authors base their example on students who have to learn some essential mechanisms of enzymes in recognizing and transforming medical drugs. The problem is introduced with two mysterious deaths in USA and Australia of people who had taken medical drugs and in which the autopsy showed a high level of medical drugs remaining in the bodies. From there, the students work with simple recognition puzzles in order to learn the specific mechanism. Afterwards, the area of enzyme mechanisms is expanded into the mechanism of transforming medical drugs. After working with these mechanism puzzles, the students should have gained the knowledge to solve the mystery of one of the deaths and thereby be able to put the newly gained essential knowledge into another context, which is also shown in the study.

Another example of how to use TDS in science education is presented by Evans & Winsløw (2007). This is an example from biology involving the reproduction of Komodo dragons (*Varanus komodoensis*). Here the essential knowledge of the didactical situation is the asexual reproduction of vertebrates called parthenogenesis. The problem is presented with the story of two different Komodo dragons in British Zoos who had asexual reproduction. The students are then given data from genetic analyses of the dragons and their offspring and data on the father and the offspring from a sexual reproduction from one of the female dragons. When the assignment is devolved, it is then up to the students to formulate a hypothesis on how this asexual reproduction could have occurred and explain the evolutionary benefits of this kind of reproduction. Based on their prior knowledge of genetics, the study shows that the students are able to realize this essential knowledge.

THE PROBLEM OF OBSERVATIONS

In the following discussion, these three examples of how to use TDS in practice will be compared in the light of observations. In a review article Eberbach and Crowley (2009) discuss the issue of how to observe and how to teach students to observe in the right way. In the analysis of what makes a good observation, they conclude that scientific observation stands on four legs, namely: (i) disciplinary knowledge, (ii) theory, (iii) practice and (iv) habits of attention. The disciplinary knowledge is knowledge on the specific subject area that the task is presented within. In the science examples, the disciplinary knowledge is the students pre-understanding of enzymes and genetics. In order to make an observation, the students must have an already existing vocabulary and already existing concepts with which to compare this new observation. This is not enough, though. The students also must have a theory in which to put these concepts. Otherwise, the observation would be just another concept or vocabulary. In having a theory as basis for observations, the students become able to see what is normal and what is different. In other words, the students have the theory as their equilibrium and a new observation could bring the students to disequilibrium if the observation does not fit into the existing theory. But one thing is theory and another is practice. It is not always as easy to observe phenomena in practice as it is described in theory. Theory is often the perfect situation and there the perfect observation is possible. However, in practice there might be many interfering disturbances that make the basis for observations more blurred. Many biologists have had the experience of looking in a microscope for the first time and seeing perfectly shaped cells, just to find out that it was air bubbles which are very common in microscopic slides. Moreover, the students' habits of attention must be trained. This is a matter of asking the right questions at the right time. In order to compare their observation with their known theory they have to know first of all what it is that they are observing. Secondly they have to ask how this works and finally they can ask questions on why it is so (Eberbach & Crowley, 2009). These four legs of observation must be coordinated and every one of them is important. If they do not work together the students could end up asking the wrong questions and looking at details not important to the essential knowledge of the subject area (Ford, 2005). Seen in this context, an observation therefore is new information acquired through the students own work and put into the existing frames of a relevant theory.

When comparing the three former cases it appears that there is a difference in the way the students observe in the different tasks. In the mathematical example the students are ask to do a task. While doing this task the students' realize that they have to use a different strategy to solve the problem. They are shaken in their own personal knowledge, and realize that they have to think differently to solve this task. The students are presented to a milieu that generates the contradictions, difficulties and disequilibria mentioned by Brousseau (1997). In both the pharmaceutical example and the biological example (which from now will be called the science examples), the students are introduced to a mysterious observation and then have to try to solve the mystery. Here the students are presented with others' contradictions, difficulties and disequilibria instead of a milieu that generates these. There is an enormous difference in these two approaches to problem solving. In the mathematical example, the students observe their own lack of knowledge. In the science examples, the students are presented with an observation that other people have made instead of making their own observations. One could say that in the science examples the teacher does the work of the action phase for the students and devolves the assignment right into the communication phase. In other words, in the math example the students are brought into disequilibrium, while in the science examples the students are being asked to go into disequilibrium. The difference between these examples lies, therefore, not so much in the difficulties in transferring TDS from mathematics education to science education, as in their introduction of observations to the students.

There might, however, also be a problem in letting the students make the observations. In the mathematical example it is obvious that a strategy of adding the extra 3 cm to each side of the bricks gives a result that physically does not fit together in a new and larger square . The observation is therefore very clear to the students. This might not be the case in the science examples. First, there is a problem in getting the students to observe two deaths in Australia and USA, or to observe two different asexual reproductions in British zoos. Secondly, if the students are provided with science examples that they can observe, there is a risk that they register whatever happens, but they do not question it. In that case, it is quite a challenge for the teacher to get them to do their own observations. In order to prevent this situation, it would be beneficial if the students are trained in making observations. An outline of this process is outside the range of this paper, but could be found in Eberbach & Crowley (2009).

CONCLUSION

When using TDS as a design tool for science education one must be aware of certain considerations. Where the observations in the mathematical situation obviously bring the students into disequilibrium this might not always be the case in science education. If a teacher relies on the students to be brought into disequilibrium within the experimental work of science classes there is a risk that the students do not question what for the trained eye seems obvious to question. In order to prevent this from happening, the teacher must ensure that the students have the proper theoretical framework in which to put their observations. One must therefore strike a careful balance between students doing their own observations and the teacher presenting the students with observations on which to focus. There is no doubt that TDS is a good tool for presenting the student with the essential knowledge of a mathematical subject area (Brousseau, 1997). The problem of transferring TDS from mathematics education to science education could be to find the fundamental situations that allow the students to make their own observations through experiments and still ensure that the students actually ask the right questions about their own experiments.

Such a setup might be found in students every-day concepts that often differ from scientific concepts. In using an every-day concept, the teacher ensures that the students have some disciplinary knowledge, some theory and some practice on which to base their observation. This would be a good basis for asking the right questions. An example from biology could be introducing the students in primary school to the fact that every living organism has respiration. A widely spread every-day concept is that animals have respiration and plants have photosynthesis. By doing experiments with photosynthesis the students get results that do not fit into their every-day concept and they therefore have to reconsider their own theory. They would be brought into disequilibrium by their own results and observations and thereby the students would be able to ask the questions themselves instead of answering questions that they did not ask in the first place. These questions would be relevant for the students, and could thereby be an entrance to develop an interest in science. In the perspective of interest development the individual who makes the observation may have a big influence. It is outside the range of this paper to outline theories of motivation (as e.g. Ryan & Deci, 2000) and interest development (as e.g. Krapp, 2002 or Hidi & Renninger, 2006) but using the students' own observations might bring more ownership into the science education (Ford, 2005). This could be an interesting topic for further investigations.

The analysis of transferring TDS from mathematics to science education is not an argument for more practical work in science education but it is a reminder that teachers have to take into consideration the purpose of the experiments. If the experiments are to bring new epistemological experiences to the students there might be good sense in letting the students do their own observations instead of relying on others' good work.

NOTES

1. Referring to the terms of digital and analogue milieu means that a digital milieu is one with either or while an analogue milieu is one with a specter within the didactical and the adidactical situations. In this case it is not a question whether the teacher interferes or helps the students but more a question to what degree the teacher does so.

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DIDACTICAL CONTRACT AND CUSTOM: ANALYTICAL CONCEPTS TO FACILITATE SUCCESSFUL IMPLEMENTATION OF ALTERNATIVES TO STANDARD PHYSICS LABS

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This paper is an inquiry into the practice of what we term 'standard physics laboratory work' in upper secondary school. We apply the concept of 'didactical contract' and 'custom' in analyzing the practice of three different Danish secondary education physics classes. The purpose is to characterise the set of 'common rules' that students necessarily infer from this practice and come to rely on in subsequent physics education laboratory settings that resemble those they have previously encountered – for instance when they start studying physics at university level and find the physics laboratory course-work resembling that of their upper secondary education. We argue that these common rules, i.e. the students' prior experience ex- and implicitly relevant to the activity, will have to be explicitly addressed if alternatives to the traditional type of physics laboratory activities are to be smoothly implemented.

INTRODUCTION

This paper sets out to investigate aspects of the praxis of 'standard physics laboratory work' in secondary education (labwork) that might impede the implementation of alternatives at later stages of education (alternative labwork). What we term labwork, is a notion closely related to Beney and Séré's (2002) description of the secondary education physics lab typical throughout Europe: "guidance through a labsheet, students working in pairs for three hours, apparatus available from the beginning of the session." (*ibid.* p. 66).

Our motivation for performing this investigation into labwork arose from having observed difficulties related to students' ability to accept the task when an alternative to the standard laboratory design was introduced at introductory level university physics. Subsequent analysis performed by the involved educators and researchers, concluded that students had difficulties understanding the ramifications of the task. It was suggested that one reason for this difficulty was that students infer a certain set of expectations from their upper secondary education about what labwork is supposed to be, that does not match the alternative labwork design. In this paper this 'set of expectations' is characterised – specifically by investigating the labwork at three different Danish secondary education school.

Before we continue with this characterisation of secondary education labwork, there will be an intermezzo in which we describe a bit further the specific incident concerning the implementation of an alternative labwork activity at university level. The reason is that this description offers a rationale and a motivation both for investigating the praxis of labwork in Danish secondary education and for our choice of theoretical framework.

Intermezzo: Clock-in-a-box

One year the group of first year students studying physics at the University of Copenhagen was at their very first encounter with the physics education laboratory asked to make a device for measuring time with the use of a selection of standard mechanics lab-equipment. The students could choose what they needed from a cardboard box, containing an assortment of springs, force meters, rulers, masses etc. The students were asked to construct a device that could measure out the passing of two minutes as precisely as possible. The designers had not planed to give further instructions, thus leaving the task as open as possible, allowing room for creativity.

As part of the design-phase, the designers of the task had invited a group of physicists who would also be part of the team of instructors, to try out the task themselves. Initially the instructors were somewhat hesitantly optimistic with regards to the purpose and outcome of such a task, but soon enough they were deeply engaged in applying to the task all sorts of physical theory and mechanical hypotheses. Reviewing their own engagement afterwards, the instructors concluded that apparently the task had stimulated them to engage with what they termed 'real physics' – in accordance with the intensions of the task-designers.

When the task was turned over to students for the first time, the instructors were surprised to see that a number of students did not engage in 'real physics' as they themselves had. Instead some students used their watches to count out how many times a spring would oscillate during a two minute interval, and suggested that counting in this manner was a viable solution to the problem. Puzzled the teachers realized that the students did not perceive this solution as cheating, but rather, as an indication that they had found an effective means of reaching the desired result – almost without applying any physics.

Naturally a posteriori analysis of the activity will yield a number of problems concerning this task. However, this is not the aim here. The activity serves as an example from which we will draw to the fore one conclusion made by the team of designers and instructors that transgress the immediate particulars of this task; namely that the reason the activity did not work as expected, was because, as they termed it at the time: 'the didactical contract had not been properly negotiated'. We will return to the notion of the didactical contract in the Theory section, but briefly, what is meant is that the teachers had not made their intentions and expectations sufficiently clear to the students. Thus the students behaved in a fashion that was surprising to the instructors. One might argue that using a watch to construct another watch is a very reasonable way to solve the problem. Since the instructors had not realized this, and since they wanted the students to utilize their knowledge of classical mechanics, they perceived of this strategy as cheating – as breaking the rules. On the other hand the students had embarked on the task expecting that the intentions were different then they actually turned out to be. This in turn, might in all likelihood have come as a surprise to the students.

Since this activity was the very first physics-lab activity the students encountered at the university, one is left wondering how they could have expected anything of the task at all. A possible answer that we will explore further is that students carry with them their experience from previous activities resembling the present. The closest activity to the 'clock-in-a-box' activity is labwork in secondary education. Since no explicit effort had been made towards negotiating the rules specific to the 'clock-in-a-box' activity, we contend that the students believed that the rules that applied during secondary education labwork also applied at university level labwork. These rules, we will call 'common rules' for lack of a better term. This term will be further developed in the Theory section; but first a research question will be stated which is subsequently framed in the larger context of research on labwork and labwork reform in the Labwork Review section.

Research Question

The notion that a didactical contract serves to establish what common rules govern what is intended with a learning activity and consequently what type of engagement one can expect of students leads us to want to know what the students come to believe about physics laboratory work in general, by doing standard laboratory work in upper secondary school physics. This, because such insight would provide us with an indication of which of those beliefs specifically clash with the expectations implied in for instance our example of an alternative labwork setting.

Thus, we formulate two research questions: What aspects of standard labwork give rise to a set of 'common rules' that contribute to students' expectations of how labwork in physics should be approached? And how can this set of common rules be characterized?

Labwork Review

Activities in school laboratories have been part of the physics education at both upper secondary school and university for about a century. The role and purpose of labwork has been discussed for just as long. Historically numerous shifts have occurred between two extremes concerning the role of labwork. Either labwork serves to help students gain conceptual knowledge of physics or the activity is supposed to help attain procedural skills (Gott and Duggan, 1995). Both perspectives on the role of labwork can readily be criticised: Investigations dating back to the 1980s show a poor conceptual outcome from labwork (Hofstein and Lunetta, 1982). On the other side it has been shown that gaining theoretical knowledge is easier and less time- and resource-consuming outside of the lab. Further, it is often argued that procedural skills have little value outside the school laboratory. For a review of this type of critique see Hodson (1993). A comprehensive analysis towards gaining a full overview of the array of normative purposes of the school laboratory as described in literature concluded with an epitome categorisation consisting of four normative purposes: procedural skills, conceptual skills, epistemological insights, and personal/social skills see Jacobsen (2008).

A third perspective on the purpose of doing labwork at school is to perceive the activity as having an own intrinsic purpose – i.e. the activity serves a goal in itself. According to this perspective understanding the nature and role of labwork and becoming proficient with working in the physics lab will be the purpose of the activity. This in turn implies a requirement for students to appropriate experimental problem solving competencies. In such a case the four normative purposes change status from being purposes and become means for students to learn to become competent solving experimental problems.

A large number of projects have set out to reform and improve laboratory activities. Often such change is aimed at including more authentic and open tasks, trying to make the students feel more like scientists than students in a school laboratory (cf. Roth, 1995, Trumper, 2002 and Karelina & Etkina, 2007). Often such alternatives are designed and implemented by engaged teachers and researchers who report that the results of these efforts are significantly improved learning outcomes and more motivated students. In the Intermezzo on the other hand we described an instance where engaged teachers and researchers tried to address students' aspiration towards becoming physicists by designing a task that from physicists' perspective appeared more authentic. Although the students were motivated, instructors perceived of some of the students' efforts to be far from satisfying.

We wish here to identify the underlying causes of this apparent collapse. Not by focusing the analysis on the alternative and on the individual participants, but by going 'behind the scene', looking into what general characteristics of the students' prior education, the common rules governing standard labwork, that can explain why expectations diverge when suddenly faced with an alternative. To do this, we need to utilize a theoretical lens through which we can perceive and analyse the common rules governing standard labwork.

THEORY

In this section we will give a somewhat comprehensive account of our theoretical underpinning. The section is divided in three parts. The first 'Contract, Custom and Desiderata' is an explication of what we mean, when we in the previous section talk about 'common rules'. The second part 'Reprise' is a synthesising recapitulation of the first section. The third part combines the first two sections with a more practically oriented approach to characterizing the contract, custom and desiderata governing the physics education lab.

Contract, Custom & Desiderata

Previously, we argued that the reason that we saw efforts fail towards improving students' outcome of and experience with laboratory work is that students and teachers had not reached an agreement on the common rules that outline the teaching and learning activity. Till now, we have not made explicit what we mean, when we talk about common rules. This is what we will do in this section.

It might be useful to start out this section by stating what distinction between teaching and learning we make use of here. One aspect of teaching is explaining or in other ways making clear to the students in a broad sense, what activity is considered appropriate for them to engage in, in order to facilitate their acquisition of a given item of knowledge. Learning on the other hand, is the students' adaptation to or compliance with this situation, in bringing the target knowledge into play in ways that allows for each student to subjectively familiarise him- or herself with the knowledge-item, making the item of knowledge their own. This distinction was made by Brousseau (1997) who name this aspect of the act teaching, as described above, *devolution*. Devolution is to hand over a task for the students to engage with. An important aspect of devolution is to assure that the task will lead the students to 'discover' a piece of knowledge (on their own) which is "entirely justified by the internal logic of the situation" (*ibid* p. 30). This of course means that a central aspect of devolution is to justify the task, and possibly make explicit the internal logic of the learning situation. That is, make explicit in what ways the task relates to what has already been learned and in some situations, what will be learned. In the case where the student does not perceive the logic of the situation devolved, the teacher and student will have to return to the process of devolution. In other words, the teacher will have to try to explain better to the student what the task might be about, and what might be expected of the student.

It might be trivial to some that student and teacher in the face of problems return to the process of devolution. Naturally a student will turn to the teacher for advice if he or she experiences having problems with the task. But for this to happen, either teacher or student will need to realize that a problem specific to the content exists. Indeed, this situation is an indication of the special relationship that exists between students and teachers that allows for specific teaching situations to be organised the way they are. It is not, however, the general pedagogical contract that governs schooling. Brousseau (1997) writes:

> [This relationship] determines – explicitly to some extent, but mainly implicitly – what each partner, the teacher and the student, will have the responsibility for managing and, in some way or other, be responsible to the other person for. This system of reciprocal obligation resembles a contract. What interests us here is the *didactical contract*, that is to say, the part of this contract which is specific to the "content" […]. (p. 31-32, italics in original)

Here Brousseau focuses on the distribution of responsibility between teacher and learner in relation to a specific content. In their interaction different roles are assigned. In a standard situation the teacher delivers to the students what general content-specific information they need to solve a problem. They in turn, will do their best to solve the problem, but the learners will also have to let the teacher know if any individual need for further information arises. Consequently the teacher is obliged to deliver this information by engaging with the students on a less general, more individual level. Accordingly the didactical contract is that system of reciprocal obligation, closely related to the content that enables the situation. In the Intermezzo we described a situation in which it appears that the situation had not been devolved sufficiently, thus, the didactical contract had not been properly negotiated (as the instructors and researchers also concluded).

As previously stated the object of teaching must be clearly defined, but also, we argue, justified. This is done in the negotiation of the didactical contract. Essentially a didactical justification is to let students know the role of the items of knowledge involved in the situation. At one instance aspects of the activity in a learning situation might involve applying an already known item of knowledge on new domains and thereby permitting insight into this new domain. At another instance the rehearsal of the application of a knowledge-item is the purpose of the activity.

This means the didactical contract can be understood as the special set of social rules that on one side defines the didactical situations in which teaching and learning takes place, and on the other side constitutes the set of rules that enables this didactical situation.

Because of this specificity of the contract to the situation Brousseau (1997) goes on explaining that no detailed general description of the reciprocal obligations can be given. That is, you cannot explain how responsibility is distributed, unless you state what it is, agents share taking the responsible for. Instead, what Brousseau finds important, is the situations in which the didactical contract breaks – the situations where the distribution of responsibility is confused, when students do not turn to the teacher for further explanation, or when students progress differently with the task than intended. As previously stated this very much resembles our experience of the clock-in-a-box incident. Unfortunately this also introduces a paradox with regards to understanding and characterizing that which are the common rules of the standard labwork setting: Brousseau would hold that such general common rules cannot be explained by the concept of a didactical contract alone. The concept is defined as specific to the content and not the general activity, whereas we claim to have seen that the effects of the rules governing the general activity of standard labwork smother the efforts towards implementation of alternatives.

Balacheff (1999) appears to have solved this paradox of ours. Balacheff noticed in his research on 7th grade mathematics learning, that some rules governing the mathematical activity had a general legislative character of a deeper and more enduring order than can be expected of the rules set by a didactical contract (Balacheff 1999, p. 25). Because these rules were very much specific to the content it does not suffice to dismiss the observed phenomenon as associated to the rules of a pedagogical or even social contract; both notions that otherwise do have this enduring quality noted by Balacheff.

Still restricted to *what is specific to content* Balacheff (1999) consequently introduces the notion of *custom*: Custom "regulates the social functioning of a given class across time", while the didactical contract has "a local character and [is restricted to] being a key element in the process of devolution" (*ibid*, p. 26).

In a related research project we observed a specific instance during a mechanics lab at the University of Copenhagen that can illustrate and add to our notion of contract and custom. The lab we observed was about Hooke's law. The students were given a somewhat comprehensive set of instructions, in which the students were asked to begin by spending some time thinking about a set of specific problems inherent to the harmonic oscillator (i.e. a mathematical description of a mass connected to a spring). Such instructions constitute the didactical contract of this particular lab. Thus, all, including the teachers and us, expected that the students would begin by engaging with these problems. However, one group of students skipped this first part, and engaged with the experimental measurements. When asked, the students explained that it was important for them to secure the required data, before engaging with interpreting it. They explained that they could always spend time at home understanding the activity, whereas getting good data, could only be done in the lab. Besides, they had been told that they were expected to engage with labwork in an individual manner, and they had decided that this way of prioritizing made sense to them. When the lab-session was over we confronted the instructor with the incident. He explained that he had noticed that this particular group had set aside the lab-instructions, but that he had not found it necessary to intervene. We infer from his statement that what happened was that the students made a decision to set aside the didactical contract – they did not breach it. Warrant for doing this was found in custom. Thus it appears that even though the didactical contract is explicitly stated, custom can at certain instances take precedence.

Still, we feel that a part is missing, before we can fully appreciate that which makes out the common rules that outline the teaching and learning situation. Namely the rules evoked in choosing the situation. Referring to Kuhn's (1983) account of how scientists make their choice between competing theories based on the scientist's professional perception of the desiderata (i.e. the 'goodness') of one theory compared to the other Christiansen *et al.* (2009) introduces the concept of shared desiderata in education:

> When engaging in teaching and learning activities, students are involved in types of […] activities that are characteristic of the scientific profession, and learn to make the same types of […] judgments in virtue of their education. […]. We […] retain Kuhn's basic

> insight, that […] while the theoretical perspective is crucial in normal scientific practice where the theory is 'taken for granted', the cultural perspective is crucial at times of theory choice. (p. 7-8)

What is argued for here is the view that the choice of teaching object or item of knowledge to be learned is very often 'taken for granted'. However, at instances where one needs to validate the choice of object, this choice is culturally validated vis-à-vis desiderata.

If we return to the previous example of two students in the lab who justified choosing data collection over spending time understanding the problem, this choice is a validation of what is important in the domain of possible activities during labwork (i.e. activities warranted by contract or custom and possibly pedagogical and social contracts). The students decided that obtaining data was more important than understanding the situation that allowed them to obtain data. Thus, this instance of domain validation tells us something about the shared desiderata in this particular physics lab; namely that obtaining data is valued over securing understanding; at least *in* the lab *performing* the experiment. Subsequent interviews revealed that the two students had engaged with understanding the problem subsequent to securing the data.

Reprise

We have now identified three dimensions that add to the common rules that outline a teaching and learning activity:

A: Reciprocal obligation.

B: Didactical justification.

C: Domain validation.

From Brousseau's notion of the didactical contract, extended to also encompass custom, a kind of implicitly standing contract, we identify A.: the reciprocal obligation of assigning responsibility between student and teacher. Also, as an important aspect of the negotiation of contract and custom is B: the didactical justification for the knowledge item at stake. Finally we use Christiansen *et al.'s* concept of shared desiderata in education as a means to domain validation: C.

In a general sense we conceptualize a separation of contract, custom and desiderata in terms of explicity. The contract is made up by the rules governing class (i.e. content engagement) that are explicitly stated (or explicitly *not* stated). The custom is that which does not need to be explicitly stated anymore. It is this, which goes without saying, because it has been said so often or clearly before. This concept we envision as the sum of the explicit didactical contracts that provide the implicit, but still content-specific rules that ensures that a teacher does not have to elaborately negotiate a didactical contract at the beginning of each lesson. Desiderata are the values (concerning content engagement) that emanates out of activity (although desiderata can be explicitly stated at some point).

A model for characterizing contract, custom and desiderata

As argued previously we interpret Balacheff's (1999) notion of custom as an analytical addition to Brousseau's (1997) notion of the didactical contract. Thus we split the didactical contract in to two parts:

1: The didactical contract as that which is explicitly stated.

2: The custom as that of the part of Brousseau's original perception of the contract which 'goes without saying', i.e. that of the contract that endures over time, present implicitly in the case of no explicit renegotiation.

This means that together with shared desiderata in education the custom is principally that set of 'common rules' this paper set out to characterise. It also means that to characterise the custom it is necessary to, not look at what is explicitly stated during a teaching activity, but to take a close look at the patterns of interaction that implicitly reveal the custom of the didactical situation. A model for doing this was developed by Hersant and Perrin-Glorian (2005). Although the model was developed with the intention of characterising mathematics teaching practice we find it applicable to characterising custom especially because of the authors' focus on characterising the teaching situation according to the way the teaching regulates the didactical contract, i.e. according to how the didactical contract can be determined from 'a characterization of a pattern of interaction' (Hersant and Perrin-Glorian 2005, p. 145).

To make this characterization Hersant and Perrin-Glorian (2005) operate with four dimensions of the didactical contract:

(1) The mathematical (in our case physical) domain.

(2) The didactical status of the knowledge.

(3) The nature and characteristics of the ongoing didactical situation.

(4) The distribution of responsibilities between the teacher and the students.

These dimensions, they state, are not independent. Instead they are an unravelling of the somewhat fuzzy content-specific social rules that make up the didactical contract.

Towards this end the authors distinguish between three levels in the structure of the didactical contract (see Figure 1): macro-, meso- and micro-contracts. These three levels correspond both to different timescales and different didactical aims.

The macro-level operates on a long-term timescale, which in the case of a labwork activity would be the entire labwork module. The meso-level accommodates the various subtasks of the labwork, such as configuration of equipment, collecting data, etc. The micro-level should correspond to very short timescale, such as in the instance the teacher answers a question posed by a student.

The didactic aims at the macro-level concern the teaching-objective of the activity, aims at the meso-level deals with the realisation of the activity, e.g. the organisation, while at the micro-level didactic aims corresponds to unities of interactions concerned with the physical content. The dimensions and levels in relations are summarised in Figure 1.

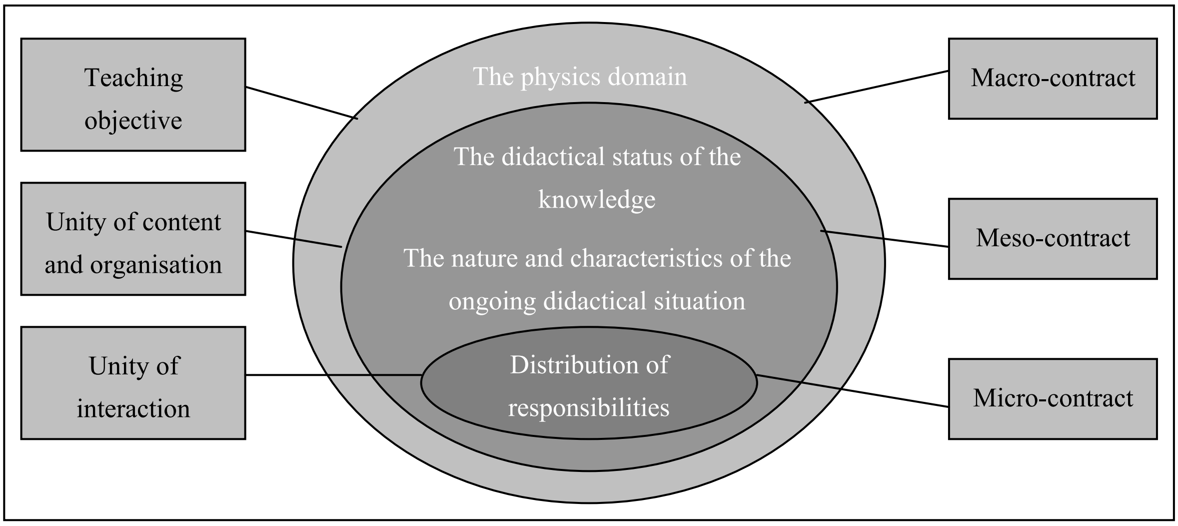

Figure 1: Structure of the didactical contract, adapted from Hersant & Perrin-Glorian 2005, p. 120.

The first dimension, the physics domain, deals with the physics knowledge to be taught. Certain types of physics domains mean teaching certain types of methods and techniques. The didactical contract of a labwork in mechanical energy differs from one in radioactivity by for instance what is found important, possible, what techniques are applied and what apparatus used etc.

The second dimension, the didactical status of the knowledge, deals with the knowledge to be learned, e.g. whether the knowledge is new or old to the students. For instance, some of the content that is applied in doing the task can be expected to be so well-established, that it can no longer be thought of as a teaching objective but rather of as a resource.

The third dimension deals with the nature and characteristics of the ongoing didactical situation in terms of the adidactical potential. The adidactical potential is the potential for students to work independently in producing knowledge. This potential is revealed by scrutiny of what of the content turns out to be utilized as a resource and what of the content offers resistances, i.e. provides actions dependent feedback to the students in engaging with the task. If the students meet no resistance in applying their resources, the task will probably be perceived as pointless. On the other hand too much resistance and no resources to apply will leave the students unable to produce any knowledge on their own.

The fourth dimension deals with how the teacher and students distribute the responsibilities within the activities at stake. E.g. in situations, where the knowledge used is new or found difficult by the students, the teacher takes on a larger piece of the responsibility compared to situations where the students are capable on their own.

Inspired by Christiansen *et al.*'s (2009) notion of shared desiderata, we wish here to add a 'zeroth' dimension to the model for the didactical contract. This dimension deals with the assigning of value to the physical domain (dimension 1) at the macro-level.

In the next section we will briefly condense this section to give an overview of the analytical framework we applied in investigating the custom characteristic for labwork at three different Danish upper secondary schools.

METHOD

We perceive of the five dimensions of the model for characterizing contract, custom and desiderata to be closely related to the three parts of the didactical contract and custom described in the Reprise: the reciprocal obligations, the didactical justification and the domain validation. Specifically we perceive of the latter to be linked to the values of the 'zeroth' dimension due to its very construct. But since a domain validation hardly makes sense if not a validation of something specific (i.e. content) we envision it connected to the physics domain. Arguably, didactical justifications will have some merits at all dimensions of our characterization of the didactical contract, custom and desiderata. However, to focus our analytical framework slightly we limit our analysis of this part to only encompass patterns of interaction related to the physical domain, the didactical status and the nature and characteristics of the ongoing didactical situations. Last but not least, in characterising reciprocal obligations we naturally look to the distribution of responsibility, but as they slightly overlap, also to the characteristics of the situation. For clarification, see Figure 2.

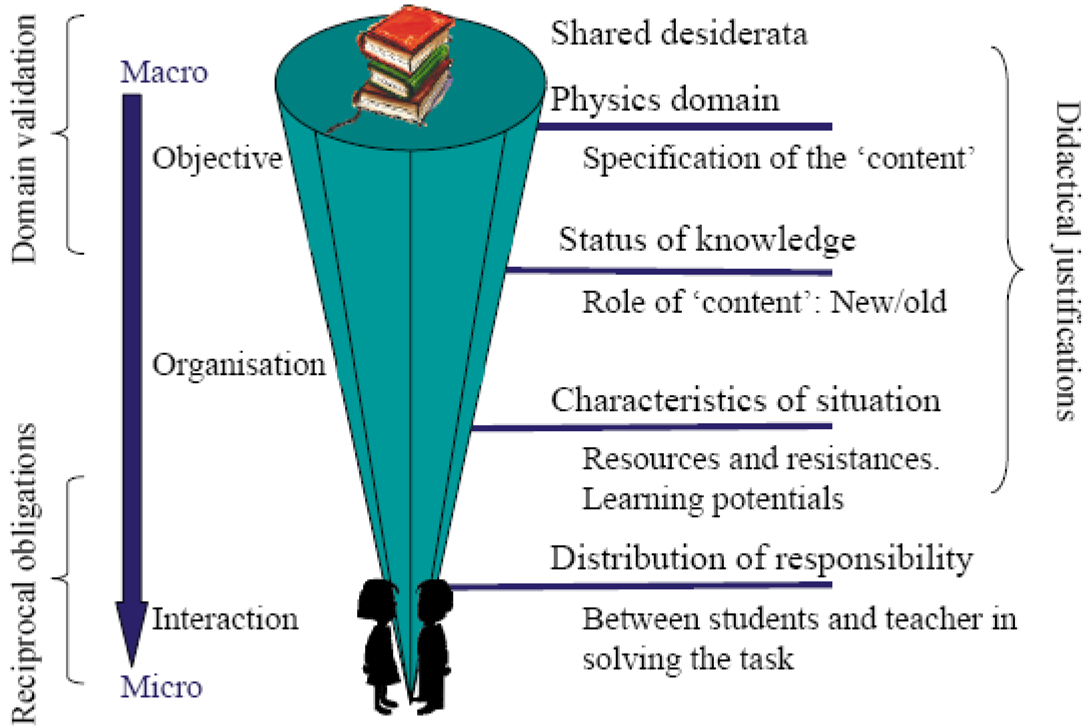

Figure 2: Analytical framework for investigating the custom characteristic for labwork.

To inform these dimensions (leading to a characterisation of the custom of labworks in physics) a comprehensive investigation of year 2 physics courses at three different Danish upper secondary schools was performed. Data comprises curriculum and task analysis, video-recordings of one labwork module at each school and of all the modules treating topics directly relevant for the labwork, student and teacher interviews and analysis of students' lab-reports. For further elaboration on methodological considerations we refer to Jacobsen (2010).

The teachers at the different schools all had different levels of experience. Their schools were chosen so as to represent as wide a socio-economical spectrum as possible while still being typical of Danish upper secondary schools. Each labwork treated a different physics topic. These choices were made to warrant at least some level of generalizability, with regards to a characterization of the custom or 'common rules' that contribute to new university physics students' expectations of how labwork in physics should be approached.

To further our claim of generalizability we look for similarities within the same dimensions of the didactical contracts but between the three labwork investigations.

RESULTS

Combining our theoretical analysis with Hersant & Perrin-Glorian's (2005) method for characterizing ordinary teaching practice, we have constructed a tool for an analysis of the patterns of interaction during labwork. By extracting similarities between three labwork activities, we characterize a custom for upper secondary school labworks. Step by step we will contrast and compare these characterizations to the alternative labwork example described in the Introduction.

Dimension Zero

The zeroth dimension concerning values or shared desiderata was informed through an analysis of student interviews and observations, which were compared to the outcome of a task-analysis according to the values expressed in and around interaction during the activity. Especially noticeable was that all labworks occurred as a verification of previously taught physical theories. Thus implicitly labwork is justified as a tool for underlining the 'correctness' of the theory: theory comes before experiment. As was the case of all labworks, data not verifying the theory are interpreted not as a falsification of the theory, but a mere result of poor data collection. Consequently such data will be rejected, or at least interpreted accordingly. As for the case of the educational value of labwork activities this 'theory before experiment' invariably instils a sense of labwork being the mere means for gaining the data necessary to further engage with physical theory.

In the alternative lab, the task is not to verify a given theory, but to measure out two minutes. The students were not given a specific theory to apply to the task. The students did not perceive this as a physical and educational sound task, since it did not follow their ideas of what constitutes valuable physics engagement. The point of the task is to find a way of being able to measure out two minutes, but not necessarily doing it. Desiderata implies realizing this point. Students who approach labwork thinking that they need to collect data in order to verify theory can only become nonplussed faced with this sort of task.

Dimension One

The first dimension, the physics domain, was informed through task-analyses focusing on what conceptual, procedural and epistemological aspects students would hypothetically need to master, in order to independently complete the prescribed labwork. When analysing the skills and knowledge needed to set up, perform, understand and report a given labwork, the results are quite complex.

The students should be able to operate on many levels of representations, be able to understand complex interplays between the mathematical model of the theory and the physical phenomena, interpreted through a setup etc. The theoretical part of the physical domain is always at the centre; no one is in doubt of what theories are to be used, since the point of the labwork is to verify a specific theory (or physical equation).

In the alternative labwork example, the phenomenon is put first, and the theories should only be used when needed. Instead of focusing on the theory part of the physics domain, students will have to apply their skills solving problems of a general nature. Such were never the requirements in upper secondary labwork tasks.

Although the problem of the alternative task by design falls within the physical domains covered by upper secondary school physics the domain plays a different role here. Specifically classical mechanics must be perceived as the mean to reach a solution to the problem of measuring out two minutes. Thus realizing how to apply classical mechanics is the goal of the task – not just measuring out two minutes in any way possible.

Dimension Two

The analysis of the second dimension, the didactical status of the knowledge, was informed through curriculum analysis, observations of teaching prior to the labwork and interviews with teachers. It shows that always, students are expected to draw upon both new and old knowledge. However, in focusing their teaching the teachers emphasize the practical handling of the apparatus, thus assigning a status to apparatus as something hitherto unknown. Data handling and interpretation is in a general sense perceived as a skill the students master. If specificities are different from business as usual, they will be covered in depth by the teacher during the briefing just before labwork is commenced.

Theory, since it is covered during the modules leading up to the labwork session, is considered known and expected fully understood at the time the labwork sessions begins.

In the alternative labwork, both the necessary knowledge and the skills necessary to engage with the task is expected by the instructors to be known. Instead it is the situation to which knowledge and skills can be applied that is unfamiliar and new.

Custom as we see above is that the teacher makes sure to explain to and explicate for the students every little aspect of the new situation. Contrary to this custom the educators in the alternative labwork did not spent time explaining what the situation entails and how theory applies, since figuring that out, was actually the purpose of the task.

Dimension Three

The third dimension, the nature and characteristics of the ongoing didactical situation, was informed by analysing observations, along with analyses of lab-reports authored by students and post-lab student interviews.

Analysis revealed that the tasks can be solved without (explicit) use of the skills and knowledge that could have appeared necessary from the analysis of Dimension One.

In practice, when students engage with the task they are supported thoroughly:

a) The labguide lays out a clear path through the labwork. Especially in facilitating the use of equipment and securing appropriate sets of data.

b) The teacher is always ready to assist throughout the activity. Especially if the equipment does not behave exactly as predicted in the labguide.

c) Students seem to rely on a form of pre-rehearsed algorithm applicable to all labwork activity – especially to writing the report that reflects the labwork activity.

Applying this algorithm (rather than an understanding of the experiment or the theory) seems to be the most important strategy when students write a report. The algorithm is as follows: Do precisely what is written in the labguide when setting up the experiment and collecting the data. Chart data in a table separating the independent and dependent variables (and possibly some kind of mathematical manipulation of some of the variables). Make a representation of the table in a graphical form which can be interpreted applying a (linear) regression. Use this regression to obtain a 'fit parameter' and compare this with the theoretically expected value. If any error, calculate it and report it as a percentage divergence. List possible sources of error (among which always mention imprecise measuring). Conclude that theory is verified through the experiment.

This custom of applying the algorithm provides the students with a shortcut through the complexity of the tasks we listed in Dimension One. The shortcut collapses the labwork to a task that does not require of the students to further their insight into the theory; the epistemology of physics; or their procedural skills – besides that which is necessary for manipulating specific equipment. The only resistance offered in the lab is to apply the algorithm to the task. All possible sources of resistance, other than unpredictable equipment are thus turned into resources.

Custom doing labwork is applying an algorithm. Faced with a task like the alternative labwork, to which the algorithm does not apply leaves the students without alternatives.

Dimension Four

The distribution of responsibility was uncovered through interaction-analyses of labwork video-recordings and teacher and student interviews. Here it was obvious how in all cases the distribution of responsibility was completely unproblematic. The students took on various roles without any negotiation. Typically one student took notes, one student read of the scale or display of the apparatus, one student changed the independent parameter etc. We bring a concrete example of two students' interactions immediately after the teacher has asked them to begin the labwork:

S1: We need a pressure gauge.

S2: I'll find it. And then measure the temperature.

[S2 leaves to find the pressure gauge. S1 turns on the PC and starts reading the labguide.]

S2: [Returns] How do you turn this thing on?

S1: [Confers the guide] There's some button on the back.

S2: OK. [looks over the shoulder of S1] what does it say here? 'Make sure the power adapter to LabPro is turned on'.

Notice that the students do not even attempt a negotiation of who does what. Nor do they touch upon the purpose of the experiment before engaging with setting it up.

In the same manner, the students-teacher relation came about smoothly; the teachers' role was primarily to help the students operate the apparatus. Another example, here the teacher is explaining to a group of students how to perform the experiment:

T: The very first thing you do, is to press collect. Then you press 'what volume'. And when you are there, it's just to press 'keep'. That's how you measure the volume exactly there at the point you want to. And then it figures out what the volume is.

The above is a very typical example of the exchange between teacher and students during the labwork. In a few cases the teacher was called upon to explain some features of the data, which did not follow the otherwise obvious functionality of the data points, for instance if one point represented graphically did not follow the curve of the other points. It is quite striking how the students do not talk physics (neither about the theory or the interpretation of the data) during their labwork. The teacher is called upon to make sure the data is collected, and in the few instances to give explanations on inconsistencies that would otherwise be a cause of problems when writing the report. How to do the report, how to interpret data, how to interpret differences between predictions and experiment etc., was never discussed.

In the alternative task, those students who were expecting that custom from labwork could be applied would probably have been at a loss. Or they would be disappointed with the instructors for not fulfilling their part of the responsibility for maintaining custom. Being used to traditional labwork at upper secondary school the viable path towards solving the alternative labwork task must be very hard to conceive of. In this light, the students who pulled out their mobile phone to get it over with, actually did take on responsibility in a situation where no one would or else wise could.

Comment

As a additional note, we find it interesting the pattern of contradictions between dimensions (0 contradicting 1, 1 contradicting 3; 2 contradicting 4). It appears to be an indication of a hierarchical relationship across the micro- to macro-levels which, if understood, could have implications for our approach to educational change. Unfortunately this is not the place to go into detail with this aspect.

CONCLUSION AND DISCUSSION

Taking departure in the theory of didactical situations we focus on the concept of the didactical contract. Applying Balacheff's modification of this concept by introducing custom, we conceptualize the didactical contract as the explicit content-specific social rules given for a certain activity, such as a labwork in physics education, while allowing for that which does not need to be stated explicitly (anymore) to become domain-specific custom. We further extend the scope of contract and custom with the concept of shared desiderata for education, ending with a three-fold characterisation of the common rules outlining a teaching situation as: reciprocal obligations, didactical justification and domain validation. Central to this account is Balacheff's modification that allows us to utilize Hersant & Perrin-Glorian's methodological tool to estimate a general custom, i.e. the common rules, outlining labwork. On all dimensions, these rules diverge with those implied by the instructions accompanying the alternative 'clock-in-a-box' labwork. This divergence, we claim, is to a large extent responsible for the failure of the clock-in-a-box lab.

We expect that failures of this sort can be avoided if instructors explicitly address the differences between the didactical contract of the specific alternative labwork and of standard labworks, emphasizing a renegotiation of the common rules that outline standard labwork. Hart *et al.* (2000) reaches a somewhat similar conclusion in ascribing the success of an alternative labs implementation to supporting students in gradually coming to understand the purpose in terms of intended learning outcomes. Our addition to this insight is that also other relevant dimensions should be articulated in the cases where these differ from the standard labwork custom.

We wish to highlight here our find that prominent of the labwork custom is the adherence to an algorithm that allows for students engaging with traditional labwork to simply shortcut every adidactical potential of the task. Thus our analysis suggests that what actual physics secondary education students might learn, is not learned in the lab. However, an aspect we have not looked into, is that there is the possibility that students in writing their report have an opportunity for reflection. This opportunity might actually lead to a learning outcome, but this, we have not investigated.

Subsequent to having investigated the standard labwork setting, we did a case study interviewing two first year physics students and a physicist who had embarked on a drastically alternative labwork trial. The task was designed as to resemble authentic research as much as possible and dire emphasis was put on a continuous negotiation of the didactical contract. We wish to end this paper by letting one of these students explain from his perspective why this lab-design appeared to have been successful:

> We set out to explore in complete darkness. But always, we knew that if we got lost our teacher was right behind us, ready to let us cling to his leg, while he led us back onto track, shedding just a bit of light on the surroundings. To be able to work like this, we really had to trust him. And we did.
>
> (Quote adapted to highlight the essence of a longer conversation)

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TEACHING NUMBER LINE, FRACTIONS, DECIMALS AND PERCENTAGES AS AN INTEGRATED SYSTEM

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Fractions and decimals have two different meanings. On the one hand they are rational numbers with concrete places on the number line. On the other hand they express ratio and relationships, which can also be expressed using percentages. Students are often puzzled which of these meanings of fractions and decimals they must use in different exercises. They probably do not understand that the reason for difficulties in these exercises lies in choosing the appropriate meaning. Therefore it is very important to introduce students to the integrated system of number line, fractions, decimals and percentages. This article presents an overview of this system, and proposes some examples and principles of the design of exercises which can be used in teaching this topic in the 6th grade.

INTRODUCTION

The teaching and learning of fractions, ratio, and proportionality is a complex process as described by many teachers and researchers (e.g. Moss, 2005; De Corte, Depaepe, Op 't Eynde & Verschaffel 2005; Adjiage & Pluvinage, 2007). On the one hand fractions and decimals can be taught as rational numbers, with a concrete location on the number line. So we can speak of the "triangle of fractions – decimals – number line" (hereafter FDN). On the other hand, fractions and decimals express ratios and

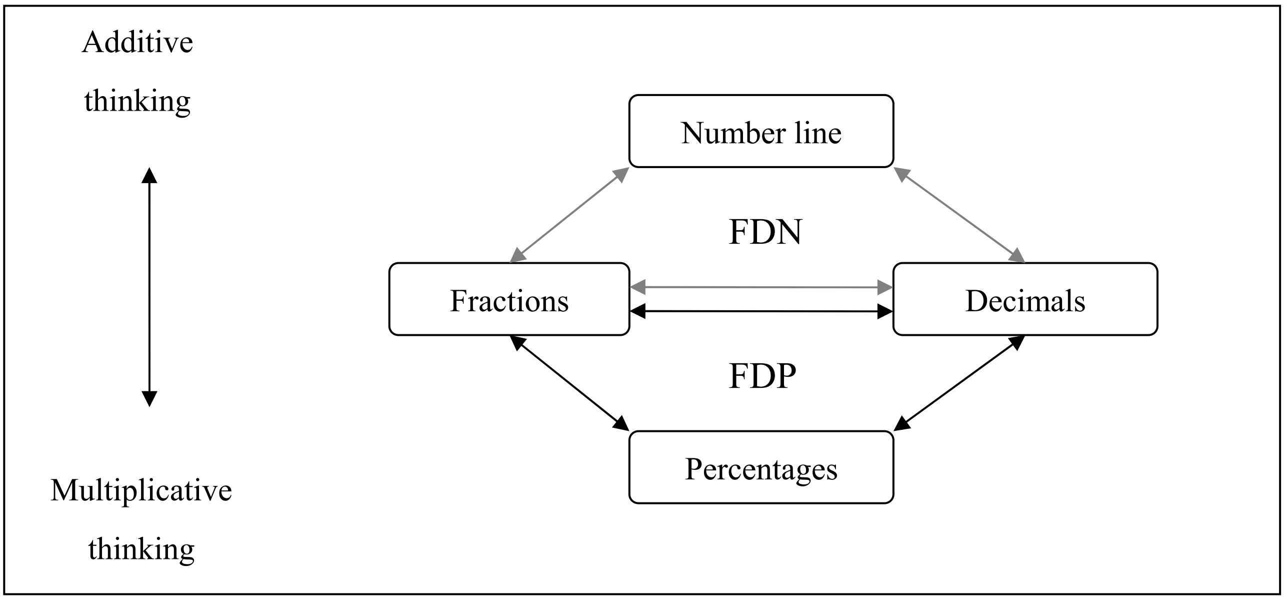

Figure 1. The number-ratio-system.

proportionalities, and are in this sense closely related with percentages. So we can speak of the "triangle of fractions – decimals – percentages" (hereafter FDP) as well (see Figure 1).

Even if students can do mathematical operations with decimals and fractions, they face difficulties when they must use decimals and fractions in sense of ratios and proportionalities (Moss, 2005). Duval (2006) points out that for students it is very difficult to change from one semiotic system to other. Thus this may lead to many mistakes and misunderstandings. According to Brousseau's Theory of Didactical Situations in Mathematics (1997) we can name such a place of accumulation of mistakes an *obstacle*: "The second main obstacle is the conception of rational numbers and decimals as ratios and then as linear mappings operating in Q," (p. 93). As the obstacle poses challenges to *didactique*, a great importance lies in the question on to overcome the obstacles most easily (Brousseau, 1997, p. 110). I think that one way to do it is to show and explain to students the whole system of "number line – fractions – decimals – percentages", and to illustrate it with examples and exercises from real life (Adjiage & Pluvinage, 2007; De Corte et al. 2005); to show when and why are we in one or the other "triangle", and how could we switch our thinking from one "triangle" to the other.

The purpose of this paper is to describe the integrated number-ratio-system (hereafter NRS), and to find suitable examples and exercises to understand it better. In the first part of this paper I present the NRS. In the second part I describe the 7th grade students' choices of transformations, and their skills in FDP. My aim is to find out, where the obstacles lie in FDP. In the third part I introduce examples from the real life, which can be used in teaching NRS, and in the last part I discuss the principles of the design of exercises linked with the NRS, which can help to overcome the arisen obstacles.

THE NUMBER-RATIO-SYSTEM

Fractions – Decimals – Number Line

Students' first contact with FDN takes place already in primary school. The number line is known from first grades as the line where at first there are only natural numbers, later whole numbers, decimals and fractions as well. It is very natural that the mathematics operations related with number line are first and foremost addition and subtraction, because these operations can be visualized easily on number line, and they can be handled as going forwards or backwards on it. It is more difficult to visualize multiplication of integers, fractions and decimals on the number line (usually the multiplication here is based on addition again), and division is almost impossible to visualize on number line. Number line mainly seems to support additive thinking (Moss, 2005).

Teaching fractions usually begins with pictures of pizzas or cakes, divided into equal pieces and some pieces are shaded or taken away. Thus, learning fractions does not usually begin on the number line, but with using various geometrical shapes. Students learn to count the number of all pieces and the number of marked pieces, and to write these two numbers to the top and to the bottom of the fraction bar as a numerator and a denominator. That kind of approach – counting – to rational numbers is also based on additive thinking (Moss, 2005). Later students discover that a particular rational number can take many forms (e.g. 3/5 = 6/10 = 18/30 = … = 0.6 = 0.60 = …), and compared to whole numbers this is a new and odd fact (Moss, 2005). According to Hannula (2003) visualizing fractions on the number line is difficult for a number of students. In my opinion, one reason for difficulties lies in learning fractions at first as parts of geometrical shapes, while later students need to visualize these parts onto number line. Duval (2006, p. 108) talks about the same problem in the notion of *changing of the semiotic system*:

> "If for any mathematical object we can use quite different kinds of semiotic representation, how can learners recognize the same represented object trough semiotic representations that are produced within different representation systems?"

My experience as a mathematics teacher says that most of students' attention goes to learning these new facts. Calculating with rational numbers is mathematical-technical acrobatics, and presumably there is not much place to think about measure (absolute thinking) or relation (relative thinking).

Fractions – Decimals – Percentages

Relative (also multiplicative) thinking, fractions and decimals related with percentages, are studied in school mathematics usually in the 6th grade (students aged 12 – 13), and it is a difficult topic for students. At first, additive thinking is deeply rooted in the previous grades. For many years additive thinking has been the norm, and now, in a relatively short time (a couple of months) students must apprehend that fractions and decimals are not only numbers on the number line (Moss, 2005) but they embody a relation and a ratio as well (Adjiage & Pluvinage, 2007).

Again, students learn fractions and decimals, but this time in the new sense – in the sense of ratio, related to the whole. These are *another* kind of fractions and decimals, although they look the same as earlier. A number of rules and algorithms are bound with this topic, and if teachers teach these rules mechanically, students do not often know, which of the rules they must use in which case. Talking about fractions, Charalambos & Pitta-Pantazi, (2007, p. 311) say:

> "…instead of rushing to provide students with different algorithms to execute operations of fractions, teachers should place more emphasis on the conceptual understanding of fractions."

Decimals are used too easily as an indicator of ratio, and using decimals in this sense in the first stage of learning ratio is a too mechanical way of calculating for students. Meaningful use of fractions instead of mechanical use of decimals would be much better (Roche, 2005).

The problems with transformations

A number of exercises on ratio are designed to mechanically train the transformations between fraction – decimal – percentage (e.g. 3/5 = 0.6 = 60%). The transformation skill is certainly important, because a lot of mistakes are done in this area. It is quite common that in case the students cannot do transformations correctly, they begin to construct answers by using the numbers that they see. Hallett (2008) found that 55% of the 13-year-olds answer to the question "Which of the following numbers: 1, 2, 19 and 21 are the closest to the sum of 12/13 + 7/8" either 19 or 21. Moss (2005, p. 313) writes:

> "One of the questions we asked was how the students would express the quantity 1/8 as a decimal. This question proved to be very challenging for many, and although the students' ability increased with age and experience, more than half of the sixth and eighth graders we surveyed asserted that as a decimal, 1/8 would be 0.8 (rather than the correct answer, 0.125)."

It can be assumed that some types of transformations are simpler for students. In order to better understand students' skills and preferences in transformations of FDP, I interviewed some students (aged 13 – 14) from the 7th grade. A short overview of the interview and its results is given in the next part of this paper.

Integrated System

As it is difficult to recognize an object written in different ways, it is also difficult to recognize two different meanings, when they are written in the same way. In both cases we are talking about changing the semiotic register (Duval, 2006). The problem of two different contents is similar to homographs in a language: when we have two words written in the same way that carry two different meanings, for example "party" and "present", it is impossible to know in which meaning these words are used. Only by adding the third word, "birthday" or "chairman" we can firmly say what the story is about. The same situation occurs in using fractions and decimals. In some cases they are just rational numbers with a certain location on number line. In some cases, related with percentages, they express a ratio (see Figure 1). Which sense we can use them in and which (additive or multiplicative) is the solving-strategy depends on the context of a concrete situation (exercise). Therefore, when students learn rational numbers as expressing the ratio and relation, it is necessary to introduce them the NRS. The key problem is to teach students (1) to understand the ambiguousness of fractions and decimals (see Charalambos & Pitta-Pantazi, 2007), and (2) to choose the right solving strategy (additive or multiplicative).

White, Wilson, Faragher, & Mitchelmore (2007) found in their study that the most complicated lesson (in the series of percentage lessons designed by them) mentioned by mathematics teachers was a lesson "How do I choose?" where students compared the appropriateness of additive versus multiplicative strategies:

> “Teachers reported being very uncomfortable with this lesson and, in fact, in one school the teacher handed over the teaching to one of the authors who was present,” (p. 812).

Thus, even teachers do not feel confident when they explain which strategy to choose. We can presume that mathematics teachers do not have a sufficient supply of good examples and exercises to work with on this topic.

THE STUDY

In the autumn of 2008 a questionnaire was carried out in seven primary schools in Estonia (N = 261 children, in 15 different classes) to test the 7th grade students’ (age 13-14) skills of percentage calculation. These students had learnt percentages in the 6th grade, and the purpose of the questionnaire was to test what they remember about calculating percentages approximately six months after learning this topic. Additionally I interviewed 10 students from this sample. In this paper I will report results from one of the questions in the interview. This question concerned all 3x2 sorts of transformations in FDP: “Which of these transformations is the simplest? Rank these transformations from the simplest to the most difficult.” The results of this question are presented in Table 1 and Table 2. One boy refused to answer this question. He claimed that he has forgotten all these transformations. Therefore I have recorded the results from nine students. All the names in the tables are pseudonyms.

To help students answer this question I used concrete examples with the numbers 3/5, 0.35 and 35%. In all three cases I used the same numbers (3 and 5), because in that case all the expressions looked similar, and the appearance did not influence the choice of order of transformation. My experience of teaching mathematics in the 6th and 7th grade says that students at this age do not apprehend that 0.35 = 35% (and the answer is ready written) but they perform every transformation separately. I presumed that some students would do transformation 3/5 = 0.35 (see Moss, 2005).

I analysed the results of the answers to this question from two aspects: students’ preferences (Table 1) and skills (Table 2) of transformations. From Table 1 it can be seen in which order the students wanted to do these transformations. The transformation from percentage to decimal had a clear preference in this sample (average 2.33). The students said that it is easy because here “simply the decimal point needs to be moved”. The next four transformations from percentage to fraction (3.11), from decimal to fraction (3.22), from decimal to percentage (3.56) and from fraction to decimal (3.78) were in medium and quite close-set. When the students got the answer 35% = 35/100 (without reducing it to 7/20), I considered it correct. The transformation from fraction to percentage (5) was considerably unpopular.

Table 1. Students' preferences of performing different transformations. Incorrect transformations are marked with a *.

transformation / student	% □ decimal 35% = 0.35	% □ fraction 35% = 7/20 or = 35/100	decimal □ fraction 0.35 = 7/20 or = 35/100	decimal □ % 0.35 = 35%	fraction □ decimals 3/5 = 0.6	fraction □ % 3/5 = 60%
1. Emilia	3.*	1.*	2.*	4.	5.	6.*
2. Harry	1.*	2.	6.	3.*	4.	5.
3. Richard	3.	4.*	1.*	2.	6.*	5*.
4. Harold	1.	6.*	3.*	4.	2.	5.
5. Rebecca	4.	1.	3.	5.	2.	6.
6. Pamela	1.	2.*	4.*	3.	6*	5.*
7. Karen	1.	5.	2.	4.	3.	6.
8. Ken	3.	4.	2.	5.	1.	6.*
9. Norma	4.	3.	6.	2.	5.	1.*
Average	1. (2.33...)	2. (3.11...)	3. (3.22…)	4. (3.55...)	5. (3.77…)	6. (5)

The easiest transformations (Table 2) are percentage – decimal (15 correct and 3 wrong answers in all), and moderately difficult are transformations decimal – fraction (12/6). The most difficult transformations are fraction – percentage (9/9) because it requires in fact a mid-transformation fraction □ decimal □ percentage. The two basic mistakes in transformations were (1) moving the decimal point only one gap instead of two gaps (35% = 3.5) or the conversion of the percentage sign not to hundredth but to tenth, (35% = 35/10 = 3.5), and (2) a combination (3/5 = 0.35) (see Moss, 2005; Hallett, 2008). The strength of the skills in transformations in FDP is shown by different arrows on the Figure 2.

From Table 1 it seems as if the students do not choose the transformations in the order of how well they master them. For example four students (Emilia, Harry, Richard and Norma) began from the transformation in which they gave an incorrect answer. I assume that the question here is not the level of mastery. These students had an incorrect subjective knowledge of this topic (Pehkonen & Pietilä, 2003), and they were sure that their answer was correct.

Table 2. Students' skills of transformations: *right (italic)* and wrong (bold) answers.

transformation / student	decimals → %	% → decimals	Fractions → decimals	decimals → fractions	% → fractions	fractions→ %
1. Emilia	*0.35 = 35%*	**35% = 3.5**	*3/5 = 3 : 5 = 0.6*	**0.35 = 35/10**	**35% = 35/10**	**3/5 = 3 : 5 = 0.6%**
2. Harry	**0.35 = 3.5%**	**35% = 3.5**	*3/5 = 0.6*	*0.35 = 35/100*	*35% = 35/100*	*3/5 = 60%*
3. Richard	*0.35 = 35%*	*35% = 0.35*	**3/5 = 0.35**	**0.35 = 3/5**	**35% = 3/5**	**3/5 = 35%**
4. Harold	*0.35 = 35%*	*35% = 0.35*	*3/5 = 0.6*	**0.35 = 3/5**	**35% = 3/5**	*3/5 = 60%*
5. Rebecca	*0.35 = 35%*	*35% = 0.35*	*3/5 = 0.6*	*0.35 = 35/100 = 7/20*	*35% = 35/100 = 7/20*	*3/5 = 60%*
6. Pamela	*0.35 = 35%*	*35% = 0.35*	**3/5 = 0.35**	**0.35 = 35/10**	**35% = 3/5**	**3/5 = 35%**
7. Karen	*0.35 = 35%*	*35% = 0.35*	*3/5 = 0.6*	*0.35 = 35/100*	*35% = 35/100*	*3/5 = 60%*
8. Ken	*0.35 = 35%*	*35% = 0.35*	*3/5 = 0.6*	*0.35 = 35/100*	*35% = 35/100*	**3/5 = 3.5%**
9. Norma	*0.35 = 35%*	*35% = 0.35*	*3/5 = 0.6*	*0.35 = 35/100*	*35% = 35/100*	**3/5 = 0.06%**
Average (right / wrong)	8/1	7/2	7/2	5/4	5/4	4/5
	15/3		12/6		9/9	

THE EXAMPLES FROM REAL LIFE

Many authors (e.g. Adjiage & Pluvinage, 2007; De Corte *et al.*, 2005; Moss, 2005) point out a necessity to introduce real-life examples and exercises in learning mathematics. De Corte *et al*. (2005, p. 2) write:

> „Powerful models have at least two important characteristics. First, they are rooted in realistic and imaginable contexts. Second, they are sufficiently flexible to be applied on a more advanced and general level. If models meet those requirements, they can bridge the gap between the informal understanding connected to the "real" and imagined reality, on the one hand, and the understanding of formal systems, on the other hand."

In Figure 2 it can be seen that in the mathematical world of the NRS there are four axes: number line – decimals, decimals – percentages, number line – fractions, and fractions – percentages. Below I will give a brief overview of each of them separately, and give a few examples from the real world which would be linked with the NRS.

Number line – decimals

On this axis the additive side of decimals appears. All the examples in which we see various scales belong in this category: rulers, thermometers, kitchen-scales, digital scales, (imaginary) sea level scale, and units of money. On this axis the quantities can be added or subtracted between themselves, and in case we have two quantities of the same kind, we can compare them in additive way (subtracting).

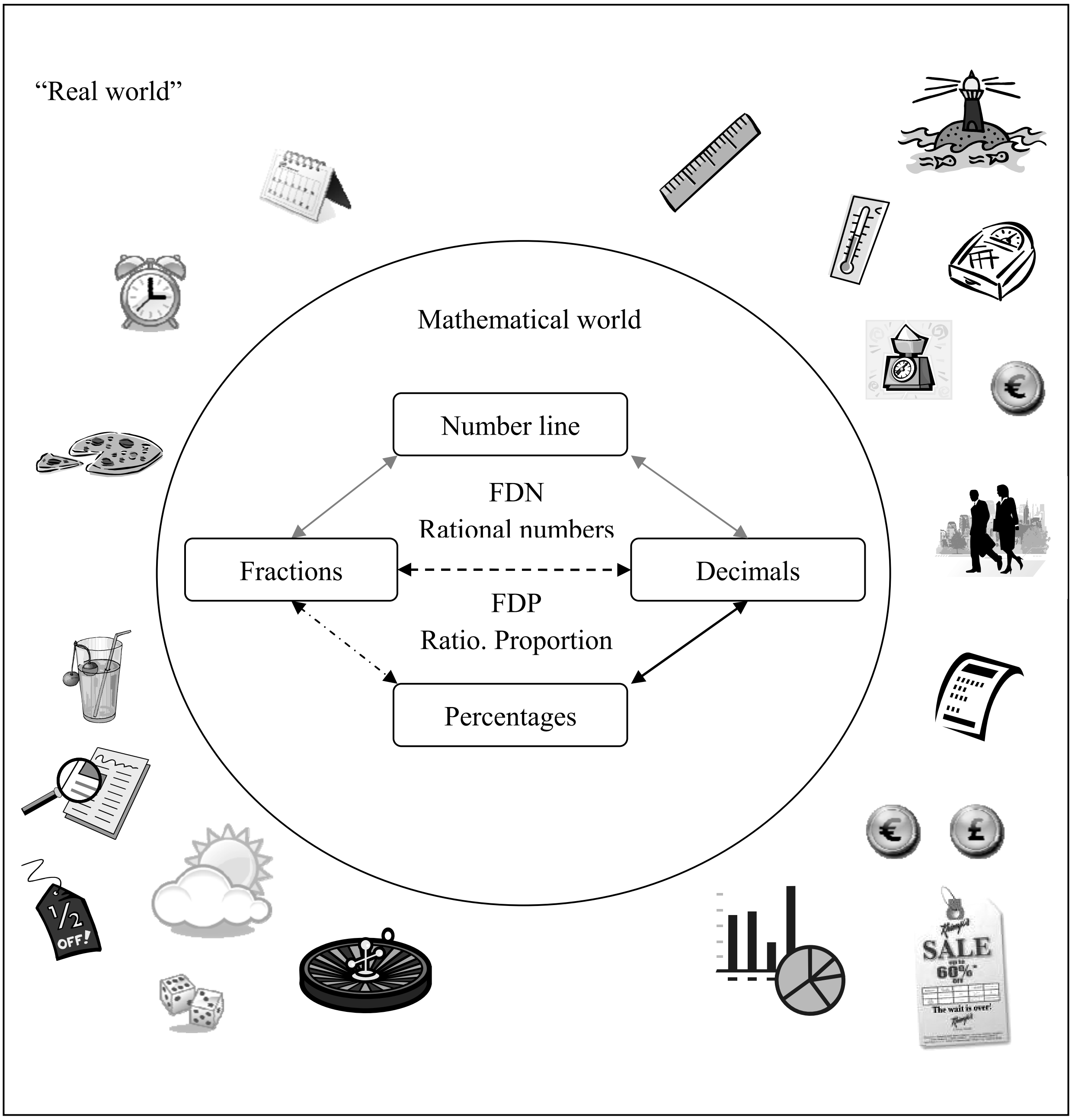

Figure 2. The "real world" and the mathematical world.

Decimals – percentages

On this axis decimals take the form of ratio. All the prior examples, where we compare two quantities of the same kind in multiplicative way (part-whole) belong in this category. In addition to these I found some examples from the real world where the decimals are ratios in their natural representation. The best example is cash receipts. For example, when we buy a piece of cheese of 0.370 kg, we see it on the receipt as 0.370 times the kilogram price of the cheese. The second example is money exchange rate. Closer to percentages are increases and falls in price or in salary. Whilst the habitual examples from statistics are usually related with big amounts, which usually need to be calculated by using a calculator that leads us to the mechanical way of calculating, in my opinion these are not good examples in the 6th grade (Reinup, 2009).

Number line - fractions

On this axis the fractions' additive side appears. Again I sought examples which were ready in the real life, not these where the fractions are artificially "created". I found only a few examples from the real life. The best example was the calendar with 12 months in a year, with 30 days in a month, and with 7 days in a week. The second example was the clock with 24 hours in a day, with a quarter to or past, and half past a full hour. A split pizza and a chocolate bar with equal pieces belong here as well, although in my opinion such examples are slightly artificial.

Fractions – percentages

In this case fractions carry the classical part-whole sense, the sense of quotient. Numerous examples fit in this category: concentration, zooming and minimizing, increase and fall in price (if we use fractions), and all sorts of probabilities.

THE CONCLUSIONS AND PRINCIPLES FOR DESIGNING EXERCISES

From the literature it is known that calculating with fractions and decimals is difficult for students (Moss, 2005; De Corte, Depaepe, Op 't Eynde & Verschaffel 2005; Adjiage & Pluvinage, 2007). On the one hand the difficulties are caused (1) by the ambiguousness of fractions and decimals (Charalambos & Pitta-Pantazi, 2007) and the necessity to change from one semiotic system to another (Duval, 2006), and (2) by pupils' poor skills in transformations of FDP (Hallett, 2008; Moss 2005).

The students I interviewed prefer transformations in the following order: first from percentage to decimal and fraction, second from decimal to fraction and percentage, and last from fraction to decimal and percentage (Table 1). Their transformation skills were the best in percentage – decimal, average in decimal – fraction, and the worst in fraction – percentage (Table 2). Typical mistakes included mechanical moving of the decimal point and combination of numbers. It is alarming that in fraction – percentage transformations, where fractions are used in their classical part-whole sense, students' transformation skills are the worst.

Adults divide the problems of ratio into many different subtypes (Charalambos & Pitta-Pantazi, 2007; Adjiage & Pluvinage, 2007). In my opinion in the 6th grade, where students learn ratio for the first time, it is important to show only two ways in principle: the additive and the multiplicative way. As a *Big Idea*, also Brigham, Wilson, Jones & Moisio (1996) suggest using ratio (division) in teaching fractions, decimals and percentages.

Knowing the theoretical base, students' transformation skills – or more precisely the locations of obstacles in their learning – and the examples from real life, linked with the NRS (Figure 2) one can design suitable exercises for teaching of the NRS. These exercises (see Example 1):

- should be exciting, fantastic or humorous situations, related with the real life, because that kind of situations encourage students to look for solutions (Schweinle, Meyer, & Turner, 2006);
- afford to ask many questions related to this situation, which include and vary both – additive and multiplicative – ways of thinking, because that kind of questions better reveal to the students the ambiguousness of fractions and decimals, and improve their abilities to change the semiotic system;
- should improve students' weak transformation skills in fractions – percentages (see Table 2; Figure 2).

Example 1.

Last month two extraterrestrial visitors, Uffo and Buffo, came to our class. At first Uffo was 80 cm and Buffo 1 m tall. When they saw that we are much taller, they decided to grow. They were very diligent; Uffo grew 60 cm and Buffo 50 cm in one month.

a) Who was taller at first? How many cm? How many percentages it was from the tallness of the shorter chap?

b) How tall are they now? Who is shorter? How many cm? How many percentages it is from the tallness of the other chap?

c) Who grew more? How many cm? How many percentages did they grow compared to their previous height? Who grew relatively more?

d) When they keep growing in the same speed, how tall will they be after one month? After one year?

e) (Etc.)

Next, more concrete exercises for teaching the NRS must be designed. Through an empirical study we will investigate, if such exercises have an effect on teaching NRS, and whether they help students to better understand the choice of the correct solving-strategy.

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ENROLLING SCIENCE TEACHERS IN CONTINUAL PROFESSIONAL DEVELOPMENT

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This theoretical paper presents a model of how science teachers working in small groups can use video to diagnose the challenges that students face when learning science content, and how they can then design and refine appropriate teaching interventions. The analysis and discussion suggest that the proposed professional development program, based around group learning, should be formatively assessed, researched and refined over time following the principles of Design Based Research, likewise the teachers' classroom interventions.

INTRODUCTION

All teaching occurs in a complex context, and science teaching also involves the imparting of highly complex content. School students' learning or lack of learning of this complex content has been discussed at length in many countries, as has the falling number of students who choose to study science beyond the age when it is a compulsory element of the curriculum (Millar et al., 2006).

What students learn is related to what and how teachers teach (Feinam-Nemser, 2001) and so also their decisions about whether or not to continue with science related subjects. Therefore supporting primary and lower secondary science teachers[1] in designing and refining their teaching so that it is aligned to the learning needs of their students could serve to address a range of problems.

One of the important characteristics in Design Based Research (Kelly, 2004) is that there should be some kind of resulting artefact that outlasts the study which can then be adopted, adapted and used by others. Iterative cycles of invention and revision are other characteristics. The hypothesis is that these principles from Design Based Research may be synthesized with what is known from research about science teachers' professional development, and that together this can lead to the development of a dynamic model which may be used in developing and implementing innovation in relation to science teachers' continual professional development.

Research Question

How can principles from design based research be used in science teachers' continual professional development?

BACKGROUND

Researchers and educators alike are aware of the gap between results from educational research and actual improvements in teaching and learning in the average classroom. When it comes to improvements in the classroom several scholars have concluded that teaching not teachers are the problem. There is no shortcut; the way forward is a long-term effort to improve teaching in the average classroom (Hiebert, Gallimore & Stiegler 2002). This must include empowerment, ideally of all members of the teaching profession, as they are all involved in the dissemination of the actual content and context. Also it is important to consider not only the development of the teachers' competences in the teaching of science, but also that their continual professional development should be meaningful and equally importantly help maintain the teachers' enthusiasm for teaching science. This is particularly important for teachers of science subjects for which there are known shortages of teachers.

THERORETICAL DISCUSSION

The theoretical discussion will have two foci: Science teachers' Professional Development (PD) and Design Based Research (DBR).

Teachers Professional Development

When it comes to teachers PD in general there is a growing consensus that it yields the best results when it is long-term, school based, collaborative, focused on student learning and linked to the curriculum (Hiebert et al 2002).

According to the review in the newest handbook of science education (Roth 2007) there is evidence that effective PD activities for pre- and in-service teachers have to:

- treat content as central and intertwined with pedagogical issues
- focus on the content and curriculum teachers will be teaching
- engage teachers actively in collaborative, long term problem-based inquiries
- enable teachers to see these issues as embedded in real classroom contexts

These principles point to organising PD activities in collaborative learning groups where the focus is on the content and context from the participants' classrooms. *Long-term* is mentioned, which suggests some form of *continual* professional development. If schools are expected to produce more powerful learning on the part of students, teachers must also be offered more powerful learning opportunities (Feinam-Nemser, 2001). She states that conventional PD programs in the US are not designed to promote complex learning by teachers or students. PD opportunities are usually sporadic and disconnected. This is the same in Denmark[1].

Each phase in the continuum of teacher learning from pre-service to experienced teacher has a unique agenda (Feinam-Nemser, 2001) beside the common principles mentioned above. Therefore any model for PD has to be dynamic and adjustable. But before looking further into this, I'll first consider the teachers' content specific professional knowledge.

Science teachers' knowledge and reflection

A wide number of research projects have looked at ways of documenting, portraying and developing teachers' professional knowledge. Attempts to articulate links between professional teacher knowledge and practice in a way that can be represented to others have, however, not always been successful, one reason being that many scholars see teacher knowledge as (partly) tacit and often topic specific knowledge. Pedagogical Content Knowledge (PCK) (Shulman, 1986) has been one of the more widely used means of describing teachers' special knowledge over the past 20 years, and though the PCK research program isn't fully cohesive the concept makes sense and has proved useful for both science education researchers and science teacher educators when talking about teachers' professional knowledge (Abell 2008). Furthermore PCK as the individual and cognitive knowledge category described in Shulman's original work has been developed in recent years to be more supportive of contemporary learning community thinking (Shulman & Shulman, 2004).

From the time of Dewey onward reflection has also been a central idea when talking about education, and the conceptualisation of reflection-in-action and reflection-on-action proposed by Schön ties reflective practice to professional practice. In contemporary research circles there is a growing consensus about the value of reflection in science teachers PD. This is grounded in the body of research knowledge about how difficult and complex it is to teach science so that all students, including those at risk of academic failure, develop meaningful understandings of central concepts and scientific ways of knowing (Roth, 2007). Furthermore the value of reflection is being further acknowledged with the understanding that learning to teach science, like learning science itself, is a process of re-evaluating and reforming one's existing theories in light of perturbing evidence (Abell & Bryan 1997).

So, reflection is considered important in teachers' PD and has relevance for their content specific knowledge, but what do we mean exactly? Reflection can be defined as *deliberate thinking about action with a view to its improvement*. Teachers' reflection requires an object, a foundation and a direction: Teachers in a learning group must have something (shared) to reflect upon and some common way of analysing it. New research has shown how use of video can contribute to developing teachers' reflective stances or *the competence of analyzing classroom events and identify often subtle differences in students understanding and the ways in which teacher actions contribute to them* (Stockero 2008). Developing a reflective stance can be supported by repeated viewing of an excerpt of a classroom interaction and fine-grained analysis of this interaction.

A model of PD using video-clubs in which groups of teachers watch and discuss videotapes of their classrooms has been demonstrated to focus discourse and reflection on students' action and ideas (Sherin & Han, 2004). Furthermore video allows teachers to reflect without a need to immediately react. French PD programs for novice teachers involve what they call 'memoir', which requires the teachers to stand back from the immediacy of their job. To use Michelle Artigue's terminology the novice teachers need regularly to be removed from '*the clamour of the immediate*' (Britton, 2003).

So from a theoretical standpoint it seems that bringing together small groups of science teachers who can video their classrooms and discuss these video segments within the group setting, is a possible frame for continual professional development. But how can this be organized? Can principles from design based research (DBR) be used?

Design Based Research & Lesson Study

The term Design Based Research (DBR) refers to a broad range of methodologies first introduced as design experiments (Brown, 1992). This approach originated in America, but there are cross-continental examples which although known by a variety of different names bear some resemblance. There are also some crosscutting features that differentiate DBR from other methodologies (Kelly (Eds), 2003). DBR, for example, has as much to do with the development of theories or 'prototheories'; as prospective or reflective actions. This leads to the characteristic iterative design approach with its continuous cycles of design, enactment, analysis and redesign. DBR includes the testing of interventions and innovations, but must also lead to sharable theories or artefacts that can be tested and used by others.

The Lesson Study format is a special Japanese form of PD, which includes the collaborative study of live classroom lessons. This approach is now spreading to some US and European educational settings (Lewis, 2004; Isoda et al 2007). In Japan Lesson Study has been used for more than one hundred years, but some of the basic principles are the same as those found in the newer international efforts of situated PD, including putting the teachers in the position of researchers[2]. Beside other resemblances the iterative dimension is crucial in Lesson Study as in DBR. A lesson study cycle involves a group of teachers and researchers and covers planning, based on a study of the curriculum and formulation of goals, the actual lesson taught by one of the teachers while others observe and collect data, and a post lesson colloquium which provides the participants with time to reflect upon and use the collected data in order to enhance student learning. Results are carried forward in a new cycle. Refinement of the actual research lesson is not regarded as the goal in itself, the small scale refinements that develop from the particular lesson under scrutiny are simply seen as snapshots of teaching and learning in general (Lewis, 2004). So the Lesson Study approach can be seen both as a pathway to developing teachers' knowledge as well as a process of articulation, enabling the participants to communicate and share this knowledge through the use of video (Hiebert et al 2002). Focusing only on the teacher's actions and the surface features in a single lesson plan instead of on students' learning, thinking and development of reasoning is, however recognised as a pitfall (Lewis 2004) of some DBR and Lesson Study approaches. This is one reason why in this study I propose the use of learning demand as a possible diagnostic level (see figure 1), which is in line with Scott et al. (2006).

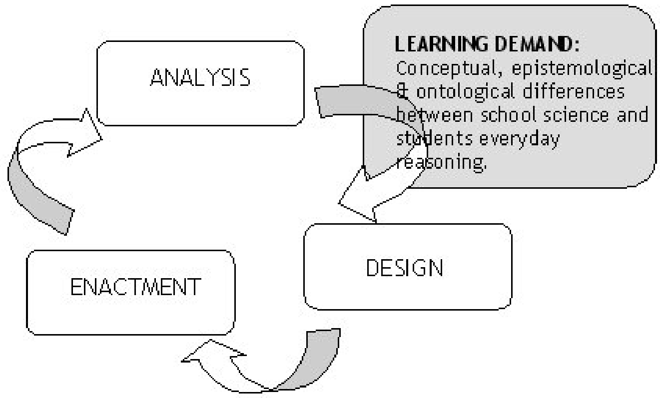

FIGURE 1: *The white boxes show the continuous cycles of design, enactment, analysis and redesign: the basic element in all Design Based Research. The grey box shows how the notion of learning demand can serve as the diagnostic level.*

The design of teaching sequences based on learning demand involves four levels:

1) Identify the school science knowledge
2) Consider the everyday reasoning of students
3) Identify the learning demand: differences (conceptual, epistemological & ontological) between 1 and 2; this is the diagnostic level shown in figure 1
4) Design a teaching intervention to address each aspect of this learning demand (teaching goals for each phase, a sequence of activities, appropriate forms of classroom communication)

Identifying learning demand as described in Scott et al. (2006) is challenging and requires the cooperation of researchers and teachers. In fact it may not be possible to import this diagnostic approach into a model designed for teachers who are working collaboratively and examining their own practice But it may be possible to include *some* of the features in an approach suited to a learning group of science teachers. For example I find that introducing a diagnostic level based on comprehensive and thorough research findings about children's pre-conceptions and everyday reasoning, a valuable addition. This also has the advantage of being relatively familiar for most Danish teachers[1] from their pre-service training.

So are there any documented models of teachers' PD that take into account students' everyday reasoning and attached learning problems?

Models of professional development through teacher inquiry

The Problem-Solving Cycle (PSC) is one approach that uses the cyclical processes characteristic of DBR. The PSC is designed to assist teachers in supporting their students' (mathematical) reasoning while developing teachers Pedagogical Content Knowledge including a critical focus on students' learning (Koellner et al, 2007). Another example is presented by Dijk & Kattman (2007) drawing on the model of educational reconstruction (Duit, Gropengiesser and Kattmann, 2005). Educational reconstruction is based on the tradition of Bildung and (Fach)didaktik which is important in German as well as in the Danish educational settings. Educational reconstruction in general involves designing learning environments in relation to the empirical study of students' pre-conceptions and a thorough analysis of the subject matter and Dijk & Kattmann are elaborating this basic model into a two-layered stack model: Educational Reconstruction in Teacher Education. The two levels of design refer to research in the classroom with involved teachers as an inner level and research in the PD of teachers as an outer level (Dijk & Kattmann, 2007).

It seems that by including design based principles in an outer level, while gradually refining the PD program, as well as including an inner level focusing on the teachers' work may be one way in which a model can be both dynamic and adjustable, attributes that were highlighted as being desirable at the beginning of this discussion. This line of argument, therefore, goes someway to answering the question of how principles from DBR can be used in science teachers' continual professional development.

CONCLUSION: A MODEL

The theoretical analysis and discussion above has provided a possible model for PD in which groups (learning groups) of science teachers plan teaching interventions based on iterative cycles of refinement. These refinements are based on a diagnostic level that involves examining their school students' pre-conceptions. This diagnostic level takes place in the individual teachers' classrooms, but discussion of the results is a group activity and forms part of the design process. Studying video-excerpts from teaching is key to this approach. Video can be analysed with a focus on the students learning of the content and serve as background for refinement of the science teaching. The work carried out by such a video learning group is designated as the inner level in figure 2.

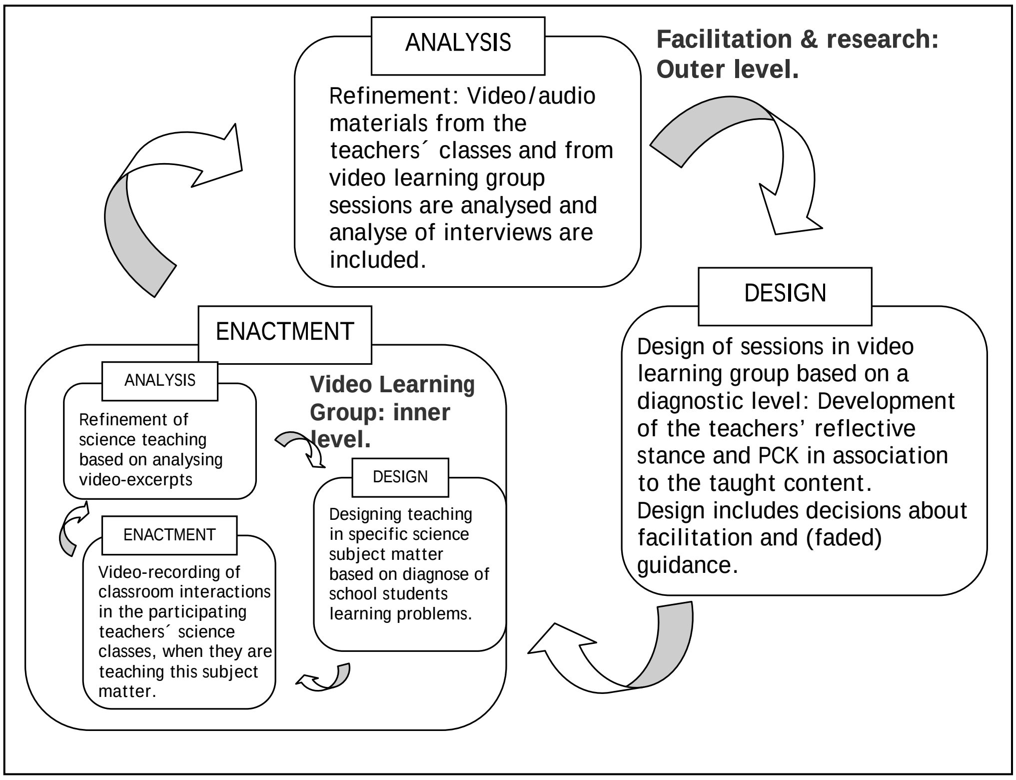

FIGURE 2: *Two levels of design. The PD activities can be formatively assessed, researched and refined (the outer level). When designing the PD activities the inner enactment level is the specific learning group of science teachers designing and refining interventions in their classrooms*

A video learning group: The inner level

In "Design" in the inner level of the model diagnosis of school students' learning problems is mentioned. Diagnostic questions can prove a useful tool when examining science pre-conceptions. A diagnostic question is one which can provide evidence of a learner's understanding of a specific idea before teaching and show how it develops through teaching, including any possible learning trajectories. The individual and social learning dimensions can be included by letting the school students write or draw their individual answer to the question or task and then afterwards discuss these individual answers in small groups, and finally a version that the group agrees upon is written/drawn[3]. The question of how to diagnose learning problems in the individual teachers' classes is meant to be discussed in the learning group and "Analysis" is situated in the learning group as well. What is learned from looking into and analyzing students learning in one teacher's classroom can of course be used in refining the teaching of this specific subject matter next time (a progression), but the collaborative dimension makes it possible for other teachers in the learning group to use the results when they are teaching the same subject matter. This emphasizes the tension between the learning of the individual teacher and the learning situated in the community of teachers as learners (Shulman & Shulman, 2004). Furthermore it illustrates how the video-clip and analysis of the students' learning can be an artefact that outlasts the study and can be shared with colleagues in the group and other science teachers.

Design and refinement of the PD activities: The outer level

The outer level of the model in figure 2 illustrates how the PD activities are designed and also the iterative cycles of refinement. It is this level that makes the model dynamic and adjustable, enabling the results from one learning group of science teachers in one school to be used when designing PD activities for other schools. For the purposes of this study, however, I will focus on a longitudinal program with the *same* group of teachers on the same school. Based on the science teachers' PD the enactment level and the facilitation can be gradually refined during a PD program. This also holds true if the outer level of the model is used as a meta-level to frame research into teachers PD.

How to go about 'measuring' the teachers' gradual PD is a challenge, and is too complex to consider in any depth within the scope of this article. Clearly there are many factors that need to be taken into consideration. In the so-called interconnected model of teachers' PD (Clarke & Hollingsworth, 2002) identification of key change domains, mediating processes, and the possible relationships between these elements are central. The thinking behind the model in figure 2 is that a possible approach to formatively assessing the teachers' PD is to use PCK as an analytical tool. Here it is important that PCK encompasses three factors: What the teacher knows, what the teacher does and the reasons for the teacher's actions (Baxter & Lederman, 1999), so data showing all these levels must be a part of the assessment. When stepping down a level in grain size (and referring to the theoretical discussion above) evaluation of the development of teachers' reflective stance can also with advantage be included in the analysis. This includes analyzing dialogue in a sequence of learning group workshops for different levels of professional reflections: describing, explaining, theorizing, confronting and restructuring (Stockero, 2008). In any case assessment of teachers gradual PD has to be multifaceted and interviews are proposed as part of the data for analysis in the outer level in the model, as well as audio/video materials from the teachers' classes and from the learning group sessions.

Finally asking the teachers' opinion of the program must be a part of the assessment as well since the aim is to create PD programs that are meaningful to teachers. At the same time it is important not to just focus on the teachers, but to provide some context for the findings so that the result is not a lot of stand-alone reports, as have been produced by some of the 'teachers as researchers' projects in the past. (Roth, 2007).

Facilitation

Based on the theoretical discussion above it seems important that the learning processes in a learning group start with questions posed *by* the involved teachers. The model in figure 2 operates with an affiliated facilitator. It is implicit that the support provided for the teachers in the group is aligned to *their* actual needs and that the facilitator can fade into the background when appropriate. Such a use of facilitation is aligned to the theoretical approaches above.

PERSPECTIVES

The next step in developing the model will be an empirical study of how the model can be used to frame and gradually refine PD activities involving science teachers. These results may lead to further discussions about the unique agenda for each phase in a continuum of PD for Danish science teachers from pre-service teacher education, through induction of novice teachers and on to in-service PD in general.

NOTES

1. The model in this paper will be used in empirical research including Danish primary and lower secondary science teachers. Lower secondary is the last compulsory element for all students in Denmark. The students specialize in upper secondary. Teachers for primary and lower secondary are trained in University Colleges, and have some similar elements in their training. Various reports looking into science in primary and lower secondary school in Denmark pinpoint the urgent need for as well qualifying pre-service education of science teachers as the in-service professional development, for example a report called "Et Fælles Loeft" from the Danish Ministry of Education.
2. The concept of (Science) Teachers as Researchers is included in a separate chapter in the handbook of science education (Roth 2007) and I refer to it as one movement, well aware that it is a headline used as an umbrella term. The definition used by Roth is *systematic, intentional inquiry by teachers about their own school and classroom work*, done with the intention of *being shared* in some way. Lesson Study is included as an example. There are according to Roth at least two bodies of current educational research that suggest an important role of the teacher: research *about* teacher learning which is the main approach referred to in this paper and teacher conducted studies *to produce sharable knowledge* for example studies about teaching particular subject matter.
3. When using diagnostic questions in this way I refer to Millar et al, 2006 and teaching resources from the EPSE project 1 http://www.york.ac.uk/depts/educ/research/PastProjects/EPSE2003/EPSE.html (accessed 27.10.09)

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AN ALTERNATIVE APPROACH FOR TEACHER EDUCATION COURSES FRAMED BY A COLLABORATE PARTNERSHIP SETTING.

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This article presents an alternative didactical approach to teacher education linking practice and theory through a collaborative partnership setting. The focus of the study is a teacher education course design which offers the opportunity for first year student teachers to move between schools and college in an iterative process in an attempt to enhance the students' development of teacher knowledge (PCK). The collaboration with the partnership schools could be described as providing the "room for study".

INTRODUCTION

A recurrent and long standing problem in teacher education around the world has been how to develop teacher education courses in which practice and theory are linked so that student and novice teachers develop the appropriate professional skills for teaching. Previously college-based teaching and field experience periods have been two more or less separated teaching situations for the students as regards to content and knowledge types, and there were often few opportunities for the students to integrate their experiences from the schools with the theories taught at college.

Linking theory and practice in teacher education is a challenge and international educational research has been dealing with this issue for many years. Partnership settings between schools and teacher education have been introduced to try and solve the problem (Furlong 1996) .The Teacher Education programme in Aarhus (LIÅ) offers such collaboration, having developed partnerships with a number of training schools.

This study is a part of a larger on-going development project concerning several approaches relevant to this partnership setting, and focuses on the possibility of offering "room for study", and so the opportunity for students to develop teacher knowledge, within the partnership setting. The aim is for the student teachers to be able to integrate college-based and school-based knowledge from the very start of their education in a way that that makes it possible for them to develop the special professional knowledge required for teaching, that is pedagogical content knowledge (PCK) (Shulman, 1986). However a collaborative partnership setting is a huge and complex frame for students, college teachers and mentors to work in, especially in a country like Denmark where there is little experience of this kind of set up in an education context. . For there to be “room for study” within the partnership setting it will be necessary to develop alternative course designs for the student teachers, that provide suitable cases or examples of didactical approaches that provide the student teachers with opportunities to develop specialist teacher knowledge (PCK) as a result of the integration of college-based and school-based training.

This sets out to provide an example of a possible design for such a teacher education programme that uses the partnership setting as “a room for study” within the collaborative frame.

RESEARCH QUESTION

Will there be evidence that the use of Co-Re and Pa-PeR[2] in a course design for student teachers, which is framed by a partnership setting, support the students’ development of aspects of PCK?

I will begin by looking at what is actually meant by teacher knowledge in terms of Pedagogical Content Knowledge (PCK). I will then describe briefly the conditions of the partnership setting that are relevant for this case study. Next I will present a didactical approach to college-based and school-based teaching in the form of a course design that exploits the “room for study” in the partnership setting. Finally I will present some evidence that this approach to teacher education offers student teachers the possibility to transform different knowledge types by integrating college-based and school-based learning and so start to develop PCK.

THEORY

What kind of knowledge is the teachers’?

In traditional teacher educational settings teacher knowledge is believed to develop through the college-based and school-based teaching and training. The fields are usually taught separately and consist of subject matter (SMK) (e.g. biology), “fachdidaktik”, pedagogics, “didaktiks” and pratice. The integration into usable teacher knowledge has to a great extent been left to the student teacher’s own initiative. This has often proved to be difficult because according to the special teacher knowledge, ideas and theories that influence student teachers’ understanding of the link

[2] Co-Re represents the structured planning of the teaching that should include several points the student teachers’ must be aware of when teaching specific content and the PaP-eR is a complementing narrative including reflections according to the teaching, the pair is called Ressource Folio (Mulhall 2003)

between theory and practice is often tacit (Schön, 1983, Korthagen 2001, Gess-Newsome 1999).

It is also an issue that has been discussed in international educational research for the last twenty years (Berry et al. 2008), starting in 1986 when Lee Shulman (1986) defined special teacherknowledge as a construct of Pedagogical Content Knowledge (PCK) that included,

> "the most powerful analogies, illustrations, examples, explanations and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (Shulman,1987, p.8)

> and further

> …that special amalgam of content and pedagogy that is uniquely the providence of teachers, their own special form of professional understanding…Pedagogical content knowledge.... identifies the distinctive bodies of knowledge for teaching.. (Shulman, 1987, p.8)

As described above, PCK is not an independent category of knowledge but a transformation, an "almalgam", of other types of knowledge such as subject matter knowledge, pedagogical knowledge and context knowledge. Teacher knowledge as PCK has been interpreted and elaborated by educational researchers: Gess-Newsome, Appelton, Van Driel, Hashwey, Loughran, Abell and others.

After twenty years of Science Education Research focused on different aspects of PCK there is a common opinion about four important characteristics of this kind of knowledge.: PCK includes discrete categories of knowledge that are applied synergistically to problems of practice; PCK is dynamic, not static; Content (science subject matter) is central to PCK; PCK involves transformation of other types of knowledge (Abell, 2008, p. 1407).These four important characteristics of PCK and the synergistic view that PCK is more than the sum of its constituent parts will be the main analytical frame for this study.

As mentioned above teacher knowledge is a different kind of knowledge to its constituent knowledge types. Korthagen et al. (1999, 2001) try and make the distinction by referring to the knowledge types defined by the ancient Greeks such as Aristotle: Episteme and Phronesis. Episteme knowledge, theory with a big "T", is based on research and the type of knowledge that is central to the field of teaching in traditional teacher education; subject matter (e.g. biology), "Fachdidaktik", pedagogy. But more often student teachers need knowledge that is situation - specific and related to the context in which they meet a problem, this type of knowledge is Phronesis, theory with a little "t", that is a more perceptual knowledge than conceptual (Korthagen 1999, p.7). Teacher knowledge (PCK) is as explained above a theory with "t" with a foundation of theories with "T", practical knowledge; Techne (praxis); and other things (e.g. ethics, emotions, tacit knowledge). All this is well illustrated by the "amalgam" metaphor (see Shulman quotation above). Teacher knowledge is not a kind of knowledge that can be studied in a book, it is to be experienced and interpreted through reflexions - in - action and reflexions - on - action (Schön, 1983). Hashweh states that:

> ” We should stress....that PCK is knowledge associated with experience, and does not seem to develop from studying in pre-service teacher education programs, at least the traditional ones” (Hashweh, 2005, p 279)

Considering the knowledge types an alternative approach to teacher education would be to turn the existing college-based teaching approach on its head and start from practice and end in theory, as described in “The Realistic Approach to Teacher Education” (Korthagen et al. 1999, 2001, 2006).

> “...the keyfactors is the relation between the schools in witch student teaching takes place and the teacher education institute. Both staff based at the teacher education institute and cooperating teachers are part of one team that supports the professional development of student teachers” (Korthagen, 2001, p. 78)

Changing from a traditional teacher educational setting to an alternative approach, in which the focus has shifted to the students’ integration and transformation of different knowledge types is a great challenge and requires the development of new content for the college-based training elements of the education programme. In addition it is important to consider the collaboration with the schools and the mentors as they will be the key to the whole approach as noted above (Korthagen , 2001). The conditions framed by a partnership setting will influence what opportunities student teachers have for transforming the different knowledge types into PCK.

The partnership setting

The 2006 reform of Danish teacher education put extra emphasis on professional development. Part of this reform specified that field experience should be the key content through all four years of the education. The professional strengthening of the education was the main reason for developing a formalized partnership setting between the schools and the teacher training college in Aarhus. The partnership setting is meant to be the frame that encompasses all three parts of the Danish teacher education programme: Subject Matter, Pedagogics and Practice.

The partnership is an agreement entered into by the training schools, the teacher training college and the municipality and is well described. In addition to the field experience period the partnership schools are obliged to involve the student teachers in other relevant activities including observations of teaching and pupils, parents meetings, staff meetings, school parties, etc. throughout the entire school year. The school-based mentors also have to take part in several meetings at the teacher training college during the year of study including planning meetings, and they are expected to take part in the preparations for the practical as well as the theoretical part of field experiences. Over all the Aarhus approach is very much in line with Furlong’s description of a collaborative partnership arrangement:

"For the partnership to succeed mentors and college teachers will need to plan some educational settings together in an on going collaboration to develop a programme for the student teachers that is integrated between college and schools "(Furlong 1996, p. 44)

However the didactical approach to the partnership setting is general and complex - one could describe it as "boulder size"[i], and one of the challenges will be to develop new approaches to the teacher training programme - at "grain size"[ii]. Teaching designs that have a 'grain size' focus with an emphasis on the student teachers' way of planning might prove to be a central issue for the partnership collaboration. Hashweh's interpretation of PCK as a collection of basic units called Teacher Pedagogical Constructions (TPC's) is a reasonable framework for this kind of small scale teaching design (Janssen et al., 2008). Planning, according to Hashweh, is central to the development of TPC's and thereby to the overall PCK development.

"Teacher pedagogical constructions result mainly from planning, but also from the interactive and post active - phases of teaching" (Hashweh, 2005, p. 277)

This article presents an example of a small scale teaching design for college-based teaching, and is inspired by Janssen et al.'s 2008 study among others. Janssen et al. explored a domain-specific heuristic for lesson planning and showed the usefulness of cyclical processes alternating between school practice and college teaching.

It would be reasonable to assume that for first year students incipient PCK could start by developing TPC's or aspects of PCK. For this to happen the college-based teaching and the school-based teaching need to be integrated by taking advantage of small scale teaching designs that alternate between schools and college and offer the students an opportunity to develop some PCK.

TEACHING DESIGN

This study offers insights into a case (Robson, 2002) of a teaching design that makes use of a partnership setting. The teaching design shows an alternative didactical approach to college-based teaching in Science & Technology to enhance student teachers' teacher knowledge.

The topic is the blood circulatory system – a teaching sequence lasting for two weeks. The design alternates between school-based and college-based teaching and the numbers refer to fig. 1.

1. The teaching sequence started in the school where the student teachers were supposed to identify some of the learning issues (Millar et al., 2006) that can arise when pupils try to understand their blood system. The student teachers asked the pupils, who ranged from 1st to 9th graders, to make a drawing of the circulatory system on a full size drawing of a body outline

2. The drawings were then presented and discussed at the college for two lessons

The main conclusion from comparing the different drawings was that most pupils knew that the heart and the blood system are connected and that the blood runs in veins but, none of the pupils, not even 9th graders, showed any knowledge of the blood running in one or two connected circulatory systems and the lungs were not drawn.

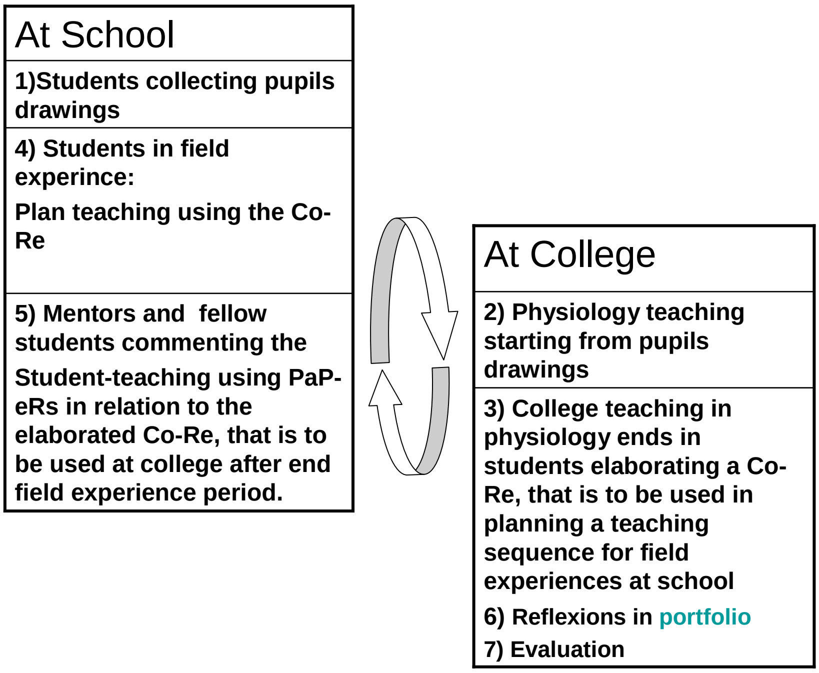

Fig.1, The cyclical process of the study alternating between college teaching and schoolpractice.

3. The SMK according to the topic was taught at college "as usual", and the educational theories considered the drawings in particular in respect of the learning demands (Millar et al., 2006).

The student teachers' assignment was to plan a teaching sequence for Nature & Technology that they could use in their up-coming field experience period. To be able to do this, the students had to develop a Content Representation - a Co-Re based on a group discussion - the same group that they were to join for fieldexperiences.

For Co-Re and PaP-eR see textbox below.

Co-Re /Pap-eR:

The Co-Re /PaP-eR were originally developed by Loughran, Berry, Mulhall (Loughran et al. 2004, Loughran, Berry and Mulhall, 2006) as a method for exploring and representing expert science teachers PCK

Co-Re represents the structured planning of the teaching that should include several points the student teachers' must be aware of when teaching specific content and the PaP-eR is a complementing narrative including reflections according to the teaching, the pair is called Ressource Folio (Mulhall 2003)

In this setting Co-Re is used in a different way to that described in the textbox above. First as a “reverse engineering project” to make the students understand how to start building up aspects of teacher knowledge (TPC), drawing upon SMK, educational theories according to pupils learning, lesson planning, evaluation and so on. The elaboration of the Co-Re was meant as a basis for the further planning of the teaching sequence. Second as a meta-theoretical approach to teaching, which was tried out by Loughran et al. (2008), who showed that it is possible to make student teachers aware of the existence of the different knowledge types in PCK.

With this approach college teaching begins with the introduction of different kinds of theories (“T”) from which the students can begin to elaborate the Co-Re. The elaborated Co-Re represents the discussed theories relating to the teaching sequence that the students are supposed to teach during the field experience period. The theories with little “t” are not relevant before the field experience as they relate to the student teachers’ experiences, and therefore the Co-Re is meant to be corrected and commented upon during the field experience period. In this way the Co-Re represents the connection between the college-based and school-based training - placed in the partnership’s “room for study”.

4. The next step for the student was to try out the teaching sequence during the field experience period. The students practice in groups of two or three and fellow students and mentors keep a diary as a narrative for reflection in the form of PaP-eR (Loughran et al., 2002) or portfolio.

5. An important part of the field experiences are the student/mentor conference meetings where the mentor discusses the students’ reflections on their teaching sequences and the teacher professional competences they have demonstrated during the period. The mentors had agreed upon giving the students supervision in relation to the Co-Re. Mentors always keep a diary of the students teaching if not a PaP - eR. Theories with “t” are prevalent here.

6. Back at college the student teachers present the main points from their field experience period according to the Co-Re /PaP-eR reflections. The college teachers build upon the mentors ‘supervision by adding theories - mostly (“T”) e.g. fachdidaktik, SMK and pedagogical theories.

7. The last part of the teaching design is for the students to reflect on the teaching in relation to the Co-Re at college after they have completed the field experience period. The students are supposed to write reflections in their field experience portfolios for the mentor and the college teacher to read and comment on. It is compulsory for the students to create this kind of portfolio, which has been selected as the overall evaluation tool in the partnership setting.

METHODOLOGY

This particular study deals with the teaching of human physiology, which is part of the “Nature & Technology” segment (a STS-subject for pupils aged 7 – 12 years). . The participants in the study are first year student teachers who have selected the Science & Technology class, and who will teach “the blood system” during their field experience according to the Co-Re” elaborated during the teaching sequence at the college. Five students and three mentors were involved in this particular study. The rest of the Science & Technology class had other topics to teach during the field experience period and made a Co-Re related to this other topic, and will not be a part of this case study.

Because this teaching design has been developed during the college teaching period by the researcher herself, there is a need for a flexible research design (Robson, 2002). As a consequence the study has an entirely qualitative research design, and the data was collected from observations of student/mentor meetings, interviews with mentors and student portfolios – various methods were used to promote triangulation. Table 1 summarizes the data collected and for which purpose: One observation with three students and two mentors and one observation with two students and one mentor. The mentors took part in a semi-structured interview (Kvale,1997) after the observations. Both observations and interviews were audiotaped and transcribed.

Table 1 Details of data collection

Participants	Data source	Timing of data collection	Purpose
Students	Observation	March 2009 Week 12 – 13	Prompts revealing types of knowledge and reflections.
	Presentation	Week 14	Prompts revealing the use of Co-Re/PaP-eR
Mentors	Observation	Week 12 – 13	Usage of teacher professional concepts during the supervision. Prompts revealing the usage of Co-Re in relation to the students learning.
	Interview	Week 12 - 13	Co-Re as a ”tool” for colaboration in the partnership setting.

In this study I am trying to elucidate if these data show some evidence of the use of Co-Re and Pa-PeR in a specific teacher education situation supporting the student teachers’ development of certain aspects of PCK, when framed by the partnership setting. The theoretical framework for analyzing the data is first of all the four characteristics of PCK identified by Abell (Abell 2008) as described above. But by taking the incipient PCK in consideration as well as particular aspects of the PCK, TPC’s (Hashweh 2005) will also be part of the framework.

In this paper I am just trying to identify examples of where there is evidence of developing teacher knowledge (TPC or aspects of PCK). As there is still data to analyse, I have decided to focus on one student teacher to see what knowledge is being developed according to the analytical frame mentioned above.

From observation 1 I have recorded a conversation between student (A) and the mentor (X) that illustrates A's reflections on practice and developing TPC for the topic under discussion:

> A: our goal is not that the pupils are supposed to describe the total blood circulatory system when we finish this topic. But they are supposed to know that the heart pumps blood and that we breathe. I know that we teach much more than this in class because it is ment for the bright pupils.
>
> X: There is no doubt that after the very intense teaching sequence about (digestion (prior topic)), where the pupils have been extraordinary interested and engaged they will not be able to show the same enthusiasm continuously. The heart dissection you made today did not have the same appeal though they absolutely took engagement in the disection. But it was difficult for them to imagine how the blood is supposed to run through the heart because it is not there, and they can not see the heart pump. That might be the reason for why the pupil engagement fell some in relation to what they showed you during the last topic
>
> A: That is what I am reflecting upon. Perhaps this topic should be for 5th – 6th form instead but the curriculum states that it ought to be 3th- 4th.
>
> Y: You could probably break the goal up in minor parts?
>
> A: Yes it should only be simple things to support the pre—conceptions. I will try to reduce this before the next lesson. Perhaps we should rethink our Co-Re

(A) has obviously experienced that theories "T" and preparation based on these do not always fit with the reality, and neither does the curriculum. It also shows the reflection process that makes A rethink the planning because of the learning demands connected to this topic were different compared to another previously taught topic.

The conversation shows the usage of theories such as SMK, fachdidaktik and professional knowledge on the basis of experience. Though it is experience shared with the mentors and the fellow student, student A shows the ability to reflect upon his planning (referring to correcting in the Co-Re), which is one of the criteria for TPC development (see Hashwey quoted above). A shows the ability to reflect upon a teaching sequence using theories "t".

A ends this particular conversation by saying:

> A: It has been a good "discussion platform" e.g. this discussion about the different hearts (animal types). One can make mis-judgments about the children's' ability for learning the subjet in a certain way but the Co-re made us focus on the theories of e.g. Piaget and discuss the dilemma of the demands from the curriculum – so now we refer to Vygotsky and we will see when the pupils have made the last drawings (evaluation tool) if we have been scaffolding enough.

This prompt illustrates that he is able to integrate Theories "T" as well in his reflections. He demonstrates that he is capable of meeting the four important characteristics of PCK (Abell 2008)

(The relation between the out takes from the conversation to the noted characteristics is bracketed):

- **Discrete categories of knowledge that are applied to practice (SMK, curricular knowledge and pedagogy are applied in the reflection on practice).**
- **That PCK is dynamic (The corrections of the CoRe and after initially referring to Piaget he then finds Vygotsy' theories more appropriate).**
- **That Content is central to PCK (Previous topic easier for pupils to understand than the blood topic).**
- **PCK involves transformation of other types of knowledge (Theories with "T" and "t" have been reflected upon in the dialogue with the mentor).**

The two mentors are recognizing the Co-Re planning and X mentions in the interview afterwards that he thinks it is suitable to collaborate within the partnership setting between school and college:

(From the interview guide)

4D Do you think it is worth proceeding with the work with Co-Re and PaP-eR as collaboration between college and schools?

> X: Very good tools and it might be possible to make it "more Danish". But we would like to mention, that it can not be as a demand put on a newly educated teacher because preparation time will not cover the time needed to elaborate it. But as a part of the college teaching it is perfect because you can use it also when the education is finished and you have well planned and reflected teaching sequences in your "bank".

CONCLUSION

What I was looking for was a new approach to college teaching - an example of a teacher education approach that is well suited for collaboration between schools and college using the partnership setting as, figuratively speaking, a "room for study" and somewhere for the student teachers to begin developing their PCK. The idea was to concentrate on a "small scale" teaching design making it possible for first year students to have a chance to begin building TPC's or aspects of PCK as a basis for further PCK development during the rest of their education and in their practice as teachers.

Though I was only able to use selected conversation segments from one student teacher to show there is evidence of developing teacher knowledge, these excerpts seem support the main idea in this article: That the use of Co-Re and PaP-eR in a "small scale teaching design" that alternates between college and schools might be a way to enhance student teachers develop aspects of (PCK) through building TPC's. This kind of college teaching requires the evolution of a new teacher education paradigm, as it turns the traditional approach to college teaching on its head. By linking theory with practice, so that the initial focus is on the practice gained as the student teachers circulate between college and school experience site. (Janssen et al., 2008) teacher education could be improved considerably. There are indications in this study that a collaborative partnership setting might constitute a "room" for this kind of teaching design and thereby enhance the students development of TPC's – collaborative partnerships could therefore be considered as a "room for study".

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TEACHER DEVELOPMENT IN THE LIGHT OF DESIGN-BASED RESEARCH METHODS

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Teacher development in a co-learning practice of inquiry is the subject of the paper. I account for the preparation of the study and discuss its design in the light of design-based research methods. The background of the study is described and research on teacher development supporting it discussed. Lesson study, a Japanese form of teacher led research approach, is discussed and compared with my intended approach.

INTRODUCTION

In this paper I account for the preparation of my intended research study with a group of eight 5th and 6th grade classroom teachers in two primary and lower secondary schools. The schools are situated in an area where there are many immigrants and families with poor background. The teachers have a desire to develop their teaching and want to be better mathematics teachers in these schools with their diverse groups of students with the goal of giving all students access to meaningful mathematics learning. The research aims at learning to understand the dilemmas the teachers are facing and how desire to improve their mathematics teaching can lead to changes that are valuable for their work.

The study involves teachers researching their own practice, with my support, and myself researching this collaborative process as a whole and my development as a researcher. As such I am working with the following research questions at the moment.

- What kind of learning processes emerges through cooperative work with teachers?
    - How do the teachers' beliefs and practices change?
    - How do the teachers perceive that participation in the project is reflected in their teaching?
    - How does the collaborative research process emerge?
- How do I perceive that I have changed as a researcher?
- How have my attitudes to the teachers practice changed and my beliefs on mathematics teacher development?

Experience from my former research of mathematics teacher development as well as the work of other researcher that have researched teacher development and the teaching and learning of mathematics has been valuable while designing the research. The goal of this paper is to reflect on the framework for my intended study and discuss it in the light of design aspects. I will account briefly for the researches that underpin the study and compare it with the key features of one form of teacher led development, the Japanese Lesson study approach.

TEACHER DEVELOPMENT IN A COMMUNITY OF INQUIRY

My intended study is a collaborative inquiry into mathematics teaching and learning (Goos, 2004) and the aim is to build a co-learning partnership between the teachers and the researcher in promoting classroom inquiry (Jaworski, 2006b) and in that way building new research methods that help us learn across boundaries. It builds on socio-cultural perspectives and an important part of it is recognition of tensions and issues and the ways in which the project learns through them.

Background of the study

Through my work as a teacher educator working with teachers at in-service, pre-service and graduate courses on mathematics education I have learned that many classroom teachers find it difficult to teach mathematics in diverse classrooms. They lack experience with investigating, communicating, reasoning and making connections and experience lack of competence in teaching mathematics for understanding in inclusive schools. Given opportunities to collaboratively investigate with mathematics and solve mathematical problems they discover how the different experiences they bring into the community contribute to their understanding of the mathematics involved and how people learn mathematics (Guðjónsdóttir & Kristinsdóttir, 2006; Gunnarsdóttir, Kristinsdóttir & Pálsdóttir, 2008). We have also found it important to model teaching that enhances inclusive education. Moore (2005) discusses the transformation from theory to practice and concludes that if teachers are expected to teach for diversity and understanding, they need opportunity to develop and enhance their pedagogical knowledge. They need to experience their own mathematics learning in an environment that reflects the environment they are expected to create in their own classroom.

Researching my own practice as primary school teacher I learned that when giving children opportunities to engage in meaningful activities, they brought new ideas into the classroom that helped all of us to gain deeper understanding of important mathematical principles and of their thinking and understanding of mathematical concepts (Kristinsdóttir, 2005). Conducting the research I was inspired by research literature on children's learning of mathematics and teacher development. Major impact on my work had the *Cognitively Guided Instruction* (CGI) project that grew from research on children's thinking about whole numbers. The project is built on an integrated program of research that focused on the development of students' mathematics thinking; on instruction that influences that development; on teachers' knowledge and beliefs that influence their instructional practices; and on the ways that teachers' knowledge, beliefs, and practices are influenced by their understanding of students' mathematical thinking (Fennema, Carpenter, Franke, Levi, Jacobs, & Empson, 1996). The researchers have continued to work with elementary school teachers to study how children learn mathematics and mathematical way of thinking. In a professional development project both school-based work-group meetings and on-site support was included. The teachers were encouraged to tell stories about the mathematics their students could do instead of focusing on what they could not do (Jacobs, Franke, Carpenter, Levi, & Battey, 2007).

Participating in a CGI course I met other teachers that were inspired to use the knowledge gained at the course in their classrooms. I asked one of them to be my critical friend and on a monthly basis we met during the three years of my study to discuss our common interest in our students learning. I videotaped both my own and her classrooms and we reflected on our experience together. Our discussions had a major impact on our development as teachers (Kristinsdóttir, 2005).

In the editorial of the Journal of Mathematics Teacher Education in September 2003 Wood & Berry discuss the need for identifying approaches to teacher education that ensure that teachers develop relative to the complexity in mathematics teaching. In spite of the continuing efforts of researchers, archived research knowledge has had little effect on the improvement of practice in the average classroom. Educators must find a way to inject new knowledge into the system of improvement and to share that knowledge with future generations of teachers (Hiebert, Gallimore, & Stigler, 2002). Teachers have a central role to play in building a useful knowledge base for the profession. Enabling teachers to learn about teaching practices and to reflect on the implications of those practices holds great promise for improving the mathematics instruction provided to all students. Teachers who want to improve their mathematics teaching need theories, empirical research, and alternative images of what implementation looks like. They need to analyze what happens when they try something new in their own teaching and record what they are learning and share that knowledge with their colleagues (Stigler & Hiebert, 2004).

Recent research on mathematics teacher development in the Nordic countries includes the Learning Communities in Mathematics–project (LCM) in Norway (Jaworski, 2007). The project "…seeks to explore ways in which classrooms can provide better learning environments for pupils in mathematics, through collaboration between teachers in schools and didacticians[iii] in the University of Agder" (Jaworski, 2007, p. 13). An important part of the analytical reporting that is central to the research in the project is recognition of tensions and issues and of the ways in which the project learns through them.

Learning from my own research and others through studying the literature on teacher development in mathematics education I have planned my research in a way that I believe will help the teachers to reach their goal of becoming better mathematics teachers in a school with a diverse group of students and give all students access to meaningful mathematics learning.

Framing the study

The study will be conducted over a period of one year. The data will include audiotapes from interviews, videotapes from workshops, notes and videotapes from classroom observations, teachers' case writings, notes from workshops, selected plans for individual lessons as well as longer periods, semesters etc. and children's work. Through the whole process I will keep a research journal and urge the teachers to do the same. From my field notes, interviews and classroom observations I hope to generate where the teachers need to strengthen their knowledge and understanding; in mathematics; about children's developments in mathematics learning; and with exploring/investigating mathematics. I will build the work in the workshops on my findings and the teachers expressed desires for improvement.

The interviews will be audio taped and transcribed. They will be semi structured (Kvale, 1996; Pring, 2000; Bryman, 2001,); I will have a few guiding questions but will be flexible and respond to the direction in which the interviewees take the interview. The purpose is to obtain descriptions of the teachers' beliefs and practices with respect to interpreting the meaning of their descriptions of their mathematics teaching and their goals with their developmental work. The metaphor of a traveller (Kvale, 1996) who explores the many domains of a country applies to my intentions with the interviews. I will critically follow up the answers and ask for specifics and clarifications. In the analysing process themes will be generated through coding (Maxwell, 2005) and used to guide me in the co-learning process.

During the first observations in each classroom I will be a participant observer (Bogdan & Biklen, 1992) and seek to be aware of the communication and the learning community established in the classroom. Themes I draw from the interviews will help me make structural questions to focus the observation (Spradley, 1980). When the developmental project has started I will videotape the lessons and use the tapes to study the lessons with the teachers in workshops. When the teachers lead class discussions I will be passive observer and while the children are working at their tasks I will walk around, observe their way of working and communicating, and discuss with them in order to get an understanding of their way of approaching the tasks. I will only write minimum of notes during the lessons, but as soon as possible after the lessons I will write them. I will also get a copy of the children's written work and take pictures of things they might make. At this point I will not videotape because I think it's important that both the teachers and the students get to know me before I start with filming. I will analyse the field notes in similar ways as the interviews and they will support me in making decisions about how to plan our work together.

When the developmental project has started I will videotape the lessons and use the tapes to study the lessons with the teachers in workshops.

The workshops will consist of mathematical explorations and discussions and reflections on them as well as discussions about teachers' stories from their classrooms and video recordings. Case writing from classroom experiences will be an important part of the teachers work to stimulate their inquiry and analysis on the real challenges and dilemmas of their practices. Describing their practice they adopt discourses for interpreting the action and construct their personal theory of the practice described. Theorized practice presents practitioners with opportunities to propose and trial new practices, make decisions or conclusions, and develop and improve their practice (Cherednichenko, & Kruger, 2006). Through refinement of their teaching I hope that spirals of experience will emerge and we can learn from former cycles while building new.

The focus of the workshops will also be on exploring with mathematics and the participants will be urged to write down their thinking. I intend to introduce them to the "spiral of building confidence "(Mason 1999, pp. 48–49) manipulating; getting sense of; capture in pictures, words and symbols; fodder for further manipulation etc. because I expect that many of the teachers are not used to explore and investigate into mathematics learning. I will find problems that have the "potential to promote mathematical activity and thinking" (Jaworski, 2007, p. 17) and stimulate collaboration where discussions and sharing thinking is meaningful.

The research is participatory and collaborative and the idea of self reflection is central to the research. Action research methods (Kemmis, 1999; McNiff, 2002) are therefore useful tools in framing the research process. The collaboration implies that the teachers and an external researcher have different roles. The teachers are the insiders because the research is focused on their practices. Insider research involves research by teachers into their own teaching. Individual research can take place in a collaborative environment involving teachers either within a school or across a number of schools (Jaworski, 2003). The outsiders may take various roles. They can help provide community of teachers and educators where the teachers can share their research practices and discuss their ideas. They may themselves conduct research into classroom learning or teaching and be engaged in research into the collaborative program. They might also be researching their own practices as educators in supporting teacher research in which case they become insiders in researching their own practice. In co-learning, the learning of one is dependent on the participation and learning of others.

According to Jaworski improvement of mathematics learning in classrooms is fundamentally related to development in teaching. Teaching develops through learning processes in communities of inquiry. She proposes inquiry as a fundamental theoretical principle and position in order to avoid perpetuation of undesirable practices (Jaworski, 2006a). She explains her framework for developmental research in mathematics teaching and learning as collaboration between teachers and didacticians to create communities of inquiry to explore development of mathematics teaching and learning. The communities allow the participants to ask questions about improving students' opportunity to learn mathematics and in doing so aim to learn about their own learning. In a community of inquiry the inquiry is seen both as a tool for developing practice and as a way of being in practice (Jaworski, 2006b)

CONTRIBUTION TO INSTRUCTIONAL IMPROVEMENT

Design research is currently receiving attention (Kelly, 2003; T. Wood, & Berry, 2003) and was discussed in year 2003 in Journal of Mathematics Teacher Education 6(3) and the Educational Researcher 32(1). Jaworski (2006a) describes the developmental research where inquiry is overtly used to design activity in the light of design research. She refers to Kelly's description of the design research as attempts to support arguments constructed around the results of active innovation and interventions in classrooms and Wood and Berries descriptions of research paradigm in teacher education. Design experiments have both a pragmatic bent—'engineering' particular forms of learning—and a theoretical orientation—developing domain specific theories by systematically studying those forms of learning and the means of supporting them (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). Building on theories of mathematics teaching and learning and my own experience of developing teaching together with others, both in elementary schools and teacher education, I hope to generate information about teacher development that is valuable for others.

Drawing on conclusions from the TIMMS[iv] video study of 8th grade mathematics classrooms in three countries Stigler & Hiebert (2004) proposed the Japanese lesson study approach as a way of improving teaching and the methods that teachers use in the classroom. It is a form of developmental work where groups of teachers meet regularly over long periods of time to work on designing, implementing, testing, and improving one or several research lessons. The results have had impact on research in mathematics teacher education and developmental projects in United States as well as other countries. Stigler and Hiebert claim that their findings about differences in teaching varying across cultures and little within cultures explain why teaching has been so resistant to change. They find it important to recognize the cultural nature of teaching and that the results give new insights into what we need to do if we wish to improve it.

Lesson study is a teacher led development, the role of the teacher and the learning environment in the classroom are in focus. The participants are in charge of both planning and implementing teaching and make decisions about the processes based on reflection on former experiences. One important factor is that the participants deepen their knowledge of the content and possible teaching approaches. They communicate, do research, work together, take decisions, plan teaching and experience the advantages of participating in a learning community. The process of lesson study is cyclic and can be described as consisting of four iterative steps of formulating goals, planning research lessons, conducting research and reflecting on data. This applies to my intended study as well. Although the teachers in my project may not all plan their lessons together the joint learning in the workshops might lead to their willingness to do so and to observe each other classrooms.

Lewis, Perry & Murata (2006) discuss how research should contribute to instructional improvement and the risk of faddism in educational research. They claim that summative trials of lesson study, while little is still known about its nature and mechanisms might contribute to making it fad. They also fear that controlled experimental research on immature versions of lesson study could lead us to conclude that it doesn't work. Drawing on examples from lesson study both in Japan and the United States they propose that three types of research are needed to avoid that it will be discarded before being fully understood or well implemented. The first is expansion of the descriptive knowledge base on lesson study to avoid misinterpretation of the approach. Secondly explication of the innovation mechanism is needed to make the innovation mechanism more visible. Models can be useful to enhance conversations about the essential features of lesson study and can stimulate sharing data and models across sites and model improvement. They may also enable innovators to adapt thoughtful and flexible approach to innovation and accompanying research. Thirdly they propose design-based research cycles. They enable researchers to progressively hone an innovation while also building theory about how it works; to develop theories, not merely to empirically tune what works. Video recordings of lessons may build the practice and theory of lesson study in several ways. It can enable researchers to identify, test, and refine key features of lesson study and test and expand our theories of professional learning. Video and other 'actionable artifacts' may capture important elements of an innovation enabling it to be enacted and studied more easily at new sites.

The goal of constructing my research with the teachers as active participants that will take part in framing our learning community is to build research methods that help us learn across boundaries. Lewis, Perry & Murata (2006) identified six important changes needed be able to effectively study locally emerging innovations in professional development, such as lesson study, changes in the structure and norms of research that will enhance its capacity are needed. Among them is recognizing "local proof" as a legitimate route to educational improvement. In Japan lesson study has been used for a century without summative evaluation. Japanese educators make their ideas about instructional design public in the form of research lessons that are observed and discussed by local and outside educators (often including university-based educators). Widely shared norms about teaching and learning begin to change when observing educators closely scrutinize both the teaching-and learning process and its rationale. School-based teacher–researchers and university-based researchers collaboratively make sense of them through discussions, sometimes reshaping their own practice and research lessons as a result. In the local proof route, both are "researchers."

Learning across boundaries is another key feature in their recommendations. Educational sites do not necessarily need to be similar to enable educators to learn from each other. Japanese education researchers have drawn extensively on practice and theory in the United States. Learning across boundaries is the capacity of researchers to learn from practitioner-initiated innovations. The authors claim that most important is the recognition of a ‘local proof route’ and that locally initiated innovations can contribute to broad instructional improvement, with education researchers supporting the explication, development, and testing of such innovations. Design-based research methods will be important to lesson study’s adaptation and testing in North America and the keys not just to the fate of lesson study but to the efficacy of education research in general.

My research together with teachers in primary schools with diverse group of students will add to research about mathematics teaching and learning. In spite of the continuing efforts of researchers, archived research knowledge has had little effect on the improvement of practice in the average classroom. Educators must find a way to inject new knowledge into the system of improvement and to share that knowledge with future generations of teachers (Hiebert, Gallimore, & Stigler, 2002). Teachers have a central role to play in building a useful knowledge base for the profession. Enabling teachers to learn about teaching practices and to reflect on the implications of those practices holds great promise for improving the mathematics instruction provided to all students. Teachers who want to improve their mathematics teaching need theories, empirical research, and alternative images of what implementation looks like. They need to analyze what happens when they try something new in their own teaching and record what they are learning and share that knowledge with their colleagues (Stigler & Hiebert, 2004).

Anna Sfard (2005) proposes mutual relationship between research and practice. The researcher’s message usually comes to the teacher in the form of a policy document, a textbook or an external examination. They rarely present the rationale for what is suggested and usually do not reflect the overall spirit of the researcher’s advice. She stresses that the responsibility for progress in mathematics teaching is the researchers and they need to work with teachers to influence the practice in schools. That is my intension with the collaboration with the teachers.

DISCUSSION

Michèle Artigue discussed didactical design in mathematics education at NORMA08 and increasing interest in design issues. She stressed that that it is important to take into account factors internal to the development of the field itself. The progression of research has made more and more evident that research methodologies have to organize a relationship with the situational, institutional and cultural dimensions of learning and teaching processes (Artigue, 2009). Researches within schools where teachers are active participants in the research process meet these requirements. The intended study meets these requirements as it builds on collaboration between teachers researching their practice and a researcher and a doctoral student researching the collaborative practice.

Design research has been discussed in several issues of the *Educational Researcher.* Shavelson, Philips, Towne & Feuer (2003) discuss three generic questions identified by a National Research Council Committee within which design studies might be appropriate: what is happening; is there a systematic effect; and why or how is it happening. The critical research Lewis, Perry & Murata (2008) call for in their article on lesson study can be seen as a mode to illuminate these questions. The Design-Based Research Collective (2003) uses the phrase design-based research methods to avoid invoking mistaken identification with experimental design. By grounding itself in the needs, constraints, and interactions of local practice, they claim that it can provide a lens for understanding how theoretical claims about teaching and learning can be transformed into effective learning in educational settings. The teachers in my study have a desire to improve their mathematics teaching in schools with diverse groups of children. By reflecting on their own understanding of mathematics and the learning community they build in their mathematics classrooms and write about their development they add to the knowledge of mathematics teaching and learning in schools. The collaboration with a researcher and a mathematics teacher educator, that motivates them to rethink their understanding of learning mathematics and their role as a teacher, focuses on their development and helps building theories about teacher development.

Lesson study is a cyclic process that has its roots in schools and systematic study of the process can help illuminate the local practice. The same applies for my intended study that is grounded in experience from the field. Describing what is happening is the intention of my research. The goal is not to trace causal effects but to try to understand processes that emerge through a developmental process and by doing so adding to the growing field of design research.

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[i] John Leach at the first session of the course.

[ii] ibid

[iii] Professionals with responsibility for theorising teaching

[iv] The Third International Mathematics and Science Study

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