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CONTEMPORARY SCIENCE EDUCATION RESEARCH: TEACHING
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Preface

This collection of papers includes scholarly works on pre-service and in-service science teacher education. There are 23 papers in part 1 while there are 25 articles in part 2. They resemble a nice blend of studies from Japan, to USA, and many countries in Europe. We are sure that the readers will find them provocative and inspiring for their own works and applications also. By looking at these articles we can find ways of improving practices in teacher education and provide suggestions for our colleagues. Thus, this book is not an end in itself but a means of further debate in the field.

We wish to thank all of the contributors in this book for their hard work.

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EDUCATIONAL RESEARCH AND TEACHING PRACTICES IN THE TEACHING OF CHEMISTRY AT SECONDARY SCHOOLS IN ARGENTINA: A PARTICULAR CASE OF CONSTRUCTION OF A SEQUENCE ON DISSOLUTIONS

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Abstract

The present communication is intended to set forth a model for the design, planning and development of a teaching sequence on the topic Dissolutions, (Domínguez Castiñeiras, 2000 and Domínguez Castiñeiras et al., 2001a) which consists of five tasks: scientific analysis; teaching analysis; selection, formulation and sequencing of objectives; teaching strategies and activity sequencing; and selection of evaluation strategies. This paper belongs to the area of Chemistry in the PCI-AECI A/019399/08, which sets up a locus of joint intervention of the researchers from the USC (Spain), and the UNL (Argentina) and the teachers at secondary schools from the latter country. The construction of this teaching sequence has first required an explicit description of the epistemological, ethical and political assumptions which underlie the educational practices and the articulation of disciplinary, pedagogical and teaching frameworks, in order to improve the teaching of Chemistry at the secondary schools in Argentina. Similarly, this process of joint construction has made it possible to reflect on the problematic knots which the content at issue presents, the selection of the contents which has to be made according to the teaching level, and the academic and administrative requirements that are essential to be able to carry out this kind of experience.

Introduction

According to Gardner (2003), it is evident that having all the knowledge we have as regards the different learning and teaching styles and types of intelligences, we cannot insist on the fact that all the students learn in the same way.

In the official syllabuses of the secondary schools in Argentina, the study of Dissolutions is included in the context of "Material Systems" and "Mixtures." It is within this framework that the use of the students' background knowledge and everyday experiences related to Dissolutions becomes relevant.

The students’ difficulties in this topic could be explained through the notions of continuity and discontinuity of the matter. That is why some authors (Gabel, Samuel, & Hunn, 1987) suggest the use of teaching strategies to describe dissolutions by means of particle diagrams. Others (Sánchez Blanco, de Pro Bueno, & Valcáreel Pérez, 1997), refer to the term dissolution as a material system or as a process.
There are numerous alternative conceptions regarding notions such as mixture and dissolution (Caamaño, 2003 and Prieto, Blanco, & González, 2000) or the incorrect use of the concept of concentration (Pozo, Gómez Crespo, Limón, & Sanz, 1991).

In this sense, it is advisable to suggest activities which take into account the hierarchy of contents. For instance, to start with the macroscopic properties of known materials, or substances and to look for the explanation in the internal order of the particles (García Barros & García Legaz, 2007).

This paper is part of some more extensive research within the project: “A shared locus of educational research and teaching practices for the construction of teaching sequences in Experimental Sciences and Mathematics”, in which research is carried out into the impact that a certain teaching proposal has on the students’ learning and its influence on the teachers’ practices.

Rationale

It is intended to carry out research into a complex subject matter that nowadays concerns a great part of the community, including the more developed countries. There is on the one hand an excessive quantity of knowledge which competes to be included in formal education, both at secondary schools and at higher education, and that has to be furthermore adjusted into the syllabus categories of separate disciplines, in our particular case, Chemistry. On the other hand, in Argentina, the teachers at non-university level have few opportunities of interacting with the scientific production of knowledge. In many cases, even though texts are accessible, they are of a high level of formalization or sometimes of a level of circulation that do not solve the main problem of transposition; that is to say, of how, what and how much to teach to secondary school students.

The proposal has entailed the joint work of teachers and researchers from both educational levels in the selection of the design, planning and development of teaching sequences according to the model put forth (Domínguez Castiñeiras, 2000 and Domínguez Castiñeiras, García Rodeja, De Pro Bueno, & Illobre González, 2001a) which consists of five tasks: determination of the academic content, determination of the learning problem; selection, formulation and sequencing of objectives; teaching strategies and activity sequencing; and selection of evaluation strategies.

Methods

As regards the methodological orientations, the students’ progressive psychological maturation was taken into account, which implies the initial treatment of more concrete concepts to be able to deal then with the more abstract ones. Likewise, the construction of analogies, not only as part of the teacher’s explanations but also as a student’s internal and active process, is a very important resource to improve the understanding of the contents and the development of scientific procedures and attitudes on the part of the students (Oliva, 2004).

The first step was the consolidation of a group of teachers from the universities and the secondary schools who made up this shared locus where educational research and teaching practices were interrelated.

Next we followed the tasks proposed by Domínguez Castiñeiras, 2000 and Domínguez Castiñeiras et al., 2001a:
1) Determination of the academic content

It places special emphasis on the functional knowledge, understood as the ability to transfer to other situations.
2) Determination of the learning problem

Depending on the planning model chosen, there are two components:

- The ideas of the students before the intervention (constructivist model).
- The cognitive requirements demanded by the subject content of learning (evolutionary model).

3) Selection, formulation and sequencing of objectives

These learning objectives are derived from the integration of scientific analysis and teaching. Its formulation meets certain skills that students are expected to achieve as a result of the learning they do, taking into account that may be developed into one teaching unit.

4) Selection of teaching strategies

It is proposed to plan the activities so as to provide opportunities for students to express their ideas. It also gives them the opportunity to differentiate between knowledge and the science proposed by the school, making explicit their findings and develop their own arguments to justify them. Since some of these ideas are resistant to change, we considered that not enough is done to raise the conflict or disagreement, but efforts are needed to introduce new ideas and apply them in different contexts.

5) Selection of evaluation strategies

It is desirable that the instruments for analyzing the evolution of learning and teaching strategy consisting of different views or dimensions.

Then we built the sequence of instruction. Following the construction of the teaching sequence (independent variable of this investigation), an agreement was formalized between the teachers-researchers from the university and the teachers from the secondary schools to implement it in three schools. Homogeneous groups of students which belong to similar educational contexts have been selected and whose teachers are part of our working group.

The sequence was implemented in three groups of Polimodal’s second year in Santa Fe city, Argentina.

The experience has begun to be evaluated using a qualitative methodology.

The data collected are being analyzed making use of emergent categories from the interviews with the teachers, before and after each activity; the students’ notebooks (thought schemata); class observations and the observation of the dialogue between the people involved in the process.

Qualitative perspective was applied to identify, through successive focalizations, the problematic knots that, according to university and secondary school teachers, the students face when trying to understand the disciplinary content. This identification was made to guide the design, implementation, observation and evaluation of the teaching sequence on the topic Dissolutions.

Results

1) Determination of the academic content

In this first task, the official curriculum considers three types of knowledge: conceptual, procedural and attitudinal:

- Conceptual: dissolution as a homogeneous mixture; classification and examples; the dissolution process: simple dispersion, solvation and chemical reaction; concentration of dissolution; dissolutions applications and dilution.
- Procedural: differentiation between observable facts and explanatory theoretical framework; experimentation and analysis of different situations obtaining a solution; selection, organization,
analysis and interpretation of information; development of critical thinking and discussion of ideas in small groups.

- Attitudinal: valuation of Natural Science for understanding and transforming the world; respect for evidence; assessment and respect for own and others' productions and sensitivity of the exchange of ideas as a source of knowledge construction.

The integration of these contents will offer students a more realistic picture of how science is constructed and its importance for the formation of citizenship.

In the curriculum of middle schools of Argentina the topic Dissolutions is addressed in the second year Polimodal within the content "Material Systems" and "mixtures" Therefore, it becomes important not only because it allows recovery of previous knowledge, but also because it reveals students’ personal expression of everyday experiences.

In order to interpret why and how solutions are produced, will be selected theories and models to go beyond the apparent knowledge of the phenomenon. The discontinuous model of matter considers that material systems are composed of interacting particles, moving and gaps exist between them. It will use the molecular-kinetic theory as an interpretative model of different states of aggregation in which dissolutions can exist. Finally, the use of molecular atomic model will affect the failure of the particle model and will be essential to interpret the diversity of matter and the distinction between mixtures and dissolutions.

2) Determination of the learning problem

Taking into account the literature, the students’ difficulties might be explained by the notions of continuity and discontinuity of matter, abundant alternative conceptions about concepts such as mixing and dissolution or the misuse of the concept of concentration.

From our teaching experience, we find many difficulties in the alternative ideas of students, such as those described by Pozo and Gómez Crespo, 1998. This occurs in relation to the limited use of the particle model of matter in explaining phenomena, assigning properties from outside world to the particles and the perception of static and continuous appearance of matter. When students are asked to represent dissolution by the macro, micro and symbolic levels, sometimes they take a continuum model for the solvent and discontinuous one for the solute.

3) Selection, formulation and sequencing of objectives

From integration of the two previous tasks makes the following objectives:

- To define the concept of dissolution as a homogeneous mixture.
- To recognize components.
- To identify the different classifications.
- To define, monitor and state an argument about the dissolution as a physical-chemical process.
- To interpret the term concentration.
- To express concentration in its different forms.
- To calculate different ways of expressing concentration.
- To distinguish the concentration of a solution of the mother and daughter.
- To determine the volume of stock solution needed to prepare dissolution of a dilute concentration.

4) Selection of teaching strategies

The teaching sequence of Dissolutions that is proposed here consists of four large sections: Mixtures, Dissolutions, Dissolution Process, Concentration and Dilution. At the same time, each of these sections is made up of the following parts: Initiation, Development and Application- in which forty three (43) activities are grouped (Domínguez Castiñeiras, Odetti, García Barros, Cajaraville Pegito, Falicoff, & Ortolani, 2007).
Initiation phase is one in which it reveals students’ personal expression of their everyday knowledge, then there is a diversified development process that leads to the synthesis of the explicit knowledge from school science. Finally there is a desirable Application of knowledge, from science education to new situations. See Table 1.

Due to the complexity inherent in the nature of the subject, work was carried out in the three conceptual levels of chemistry (Johnstone, 1982). For this purpose, a series of activities was set up to deal with the macroscopic, microscopic and symbolic levels and, for each one, notes and suggestions for the teachers were written down. The following are interesting examples of the section Dissolution Process:

(A 12, Initiation) Playing "at seeing" the particles in dissolutions

To see the particles in dissolutions, try the following experience:

Add a spoonful of glucose, the sugar that can be found in fruit and honey, to a precipitation glass with water. See what happens, describe it and try to explain it in your own words.

Afterwards, repeat the experience with table salt. Describe what happens and explain it in detail.

Try to represent what you have watched experimentally with little balls or clips of different colors. Then, in a piece of paper, make a sketch to represent it.

Activity intention

It aims to work with two types of substances that, when dissolved, have different characteristics and where the solute particles are arranged evenly between the water without reacting with each other. Before and after preparing the solution, the substances are the same. When is an ionic substance, the ions that are separate are distributed evenly in the water. For molecular substances such as glucose, is the same molecule that is dispersed in the solvent. Using certain elements in the case of "view" on the macroscopic level what happens at the microscopic level, to make explicit the ideas of microscopic representation model for the various ions in the case of salts and /or molecules in the case of molecular substances. It seeks to facilitate the realization that in the process of forming a solution of the solute particles are intimately mixed with the solvent and it is determined not only by the individual characteristics of the solute and solvent but also by the different interactions between the components of the solution. It promotes recognition of the processes leading to obtaining a solution which can be divided into three groups: simple dispersion (glucose), solvation (table salt) and chemical reaction.

See Figure 1, and Figure 2 below.

It intends to use the microscopic and symbolic representation.

![Simple dispersion](image)

**Figure 1. Simple dispersion.** (The dotted lines indicate the interaction of water molecules with glucose).
(A 17, Development) Search a large crystallizer in the laboratory, put water up to half and a few drops of phenolphthalein. Now add a small piece of sodium or potassium. Work with great care and use security features. See what happens.

Activity intention

It is desired that students learn that when we add a small amount of sodium to the water, a violent reaction occurs. It forms hydrogen gas and sodium hydroxide, the heat released in the reaction is sufficient to melt the sodium, which has not yet reacted, in the form of a sphere. The solution containing phenolphthalein turns to pink by the appearance of hydroxyl ions. Metal dissolution occurs but through a chemical reaction.

It should be noted that in this type of production process of a solution, you achieve a homogeneous mixture of the initial components but they react with each other (chemical reaction) and gives rise to a new homogeneous mixture whose components are the products of above reaction.

It favors the explanation at the microscopic level and the symbolic representation.

See figure 3.

\[
2 \text{Na(s)} + 2 \text{H}_2\text{O(l)} \rightarrow 2 \text{NaOH(aq)} + \text{H}_2(\text{g})
\]

Figure 3. Chemical reaction.
(A 18, Application) If now we mix with 100g water 40g of coffee in a bowl and stirred until it dissolves completely, giving a dark solution. Draw:

A. Situation to the macroscopic level.
B. Make a microscopic level diagram that represents what happens when doing the mix.
C. What about coffee? Draw a cross in the correct /s option/s:
   a) It reacts with water to form a new substance that gives flavor to coffee.
   b) It has become a new substance to pass to a liquid state.
   c) It maintains its identity but it’s dissolved in the liquid.
   d) It disappears in the water.
   e) It is present but in smaller amounts.
   f) It is present but in greater quantity.
   Justify your answers.

Activity intention

It aims to work the concepts of conservation of mass to obtain a solution; the total mass of solution equals the sum of the masses of individual components. Students can discuss how to modify the microscopic representation of the solvent and solute when dissolved in one another.

It promotes the exchange of ideas as a source of knowledge construction.

Table 1. Sections, parts and number of activities of the teaching sequence (Domínguez Castiñeiras et al., 2007).

<table>
<thead>
<tr>
<th>SECTIONS</th>
<th>PARTS</th>
<th>NUMBER OF ACTIVITIES (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixtures</td>
<td>Initiation</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Development</td>
<td>2,3</td>
</tr>
<tr>
<td></td>
<td>Application</td>
<td>4,5,6,7</td>
</tr>
<tr>
<td></td>
<td>Initiation</td>
<td>8</td>
</tr>
<tr>
<td>Dissolutions</td>
<td>Development</td>
<td>9,10</td>
</tr>
<tr>
<td></td>
<td>Application</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Initiation</td>
<td>12,13,14</td>
</tr>
<tr>
<td>Dissolution process</td>
<td>Development</td>
<td>15,16,17</td>
</tr>
<tr>
<td></td>
<td>Application</td>
<td>18,19,20,21</td>
</tr>
<tr>
<td></td>
<td>Initiation</td>
<td>22,23,24</td>
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<tr>
<td>Concentration</td>
<td>Development</td>
<td>25,26,27,28,29, 30,31,32,33,34</td>
</tr>
<tr>
<td></td>
<td>Application</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Initiation</td>
<td>36</td>
</tr>
<tr>
<td>Dilution</td>
<td>Development</td>
<td>37,38,39,40,41</td>
</tr>
<tr>
<td></td>
<td>Application</td>
<td>42,43</td>
</tr>
</tbody>
</table>
5) Selection of evaluation strategies

The information collected is being analyzed from different viewpoints or dimensions:

- The sections of students (patterns of thought).
- Surveys to teachers before and after each activity.
- Recording and observation of classes.
- Dialogue with the actors involved in the process.

As we have already said it was designed and planned materials for teachers and for students. Such materials or booklets were the instruments for gathering information. To track the students, we have been developed, thought patterns from their written speech (Domínguez Castineiras et al., 2005). For that reason, we have defined the schema reference from school science. In this way you get a list of links used by each student in the different activities proposed. Such relationships have been categorized according to whether they are coincident or not with the science school. We have only considered the production of written material in their work.

As indicated above, we identified the relationship between the reference pattern and the variables in the productions of the students. We can get or obtain appropriate frequencies. In addition, a questionnaire designed to know the opinion of the teacher on the sequence before and after the intervention in the classroom and an observation sheet. The contrast of views will be interesting to compare the initial teacher thinking with the result of education.

Conclusions and Implications

This proposal has made it feasible to consolidate the work in teams. This process has not been exempt from difficulties which were mainly related to the internal logic of the different institutions involved in the research process. It was possible to overcome these difficulties thanks to the trust built among the team members. This joint endeavour enabled the different levels involved, university and secondary, to provide each other with feedback throughout the process. At the same time, the successive meetings have promoted debates and reflection – epistemological, educational and historical- on the contents.

It has begun to evaluate the experience through a qualitative methodology it tries to analyze, whether the impact on student learning and teaching practices of teachers. Although we do not have definite numbers yet, this is what we have seen up to now:

- The proposal promotes and creates a classroom atmosphere in which students are actors and the role of the teacher is to help and guide.
- Significant number of students has turned relationships desirable from school science: the dissolution as a homogeneous mixture and process, the recognition of the solute and solvent in various proportions; the nature of them is what regulates the process of dissolution.
- Some misconceptions persist.
- The number of proposed activities is high.
- Time for institutional demands or requirements, influence the teaching process and student learning.

So far, we have been able to observe that the proposal has promoted changes in the students’ attitude towards knowledge -they are now the leading actors of their own learning process. Within this framework, the strategies developed by teachers and students have implied: greater dedication, new questions, and new ways of providing explanations for complex processes, different ways of working with the theoretical and the empirical levels and a more rigorous use of the language.
References


Gratitude

THE DEVELOPMENT OF (STUDENT) TEACHERS` BELIEFS ABOUT TEACHING SCIENCE

A MULTI-PAPER SET

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CURRICULUM AND TEACHING IDEAS OF PRE-SERVICE CHEMISTRY TEACHERS IN A CONTEXT OF EDUCATIONAL REFORM IN BRAZIL

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Abstract

This research reports on a study that evaluated the conceptions of chemistry curriculum and teaching plannings for secondary level for undergraduate students in a Chemistry Teacher Education Program in the University of Sao Paulo, Brazil. This group of twenty three pre-service teachers was observed during a one-semester Chemistry Teaching Methodology discipline, which joins chemical and pedagogical knowledge. This work focuses on the understanding of pre-service teachers’ beliefs related to education, their visions on teaching and teachers, and their conceptions on the ideal chemistry curriculum and its role. Teaching plannings and interviews were investigated, analyzed and categorized. Our study demonstrates how the Brazilian educational reform and the characteristics of the national educational guidelines impact teachers’ beliefs on education, learning processes, curriculum and teaching. Analyses of the interviews reveal the students motivation for pursuing a teaching career, their understanding of the teaching profession and the role of teacher educational programs. Curriculum beliefs regarding importance of chemistry on secondary education and the role of the university entrance exam were also investigated.

Introduction

Teachers play a crucial role in the curriculum innovation. In 1996, a large educational reform in Brazil with new pedagogical guidelines started. As other developing countries, Brazil demonstrates an unknown number of problems related to education, even though the Government has addressed part of them. According to Rogan (2005), although in many cases the educational reforms are well designed in developing countries, problems occur during the implementation process, preventing significant results from being accomplished. The ongoing Brazilian Educational Legislation focuses on both general and specific education for the Secondary Level (15-17 year-old students). The legislation also expects that Teacher’s Education Programs should form professionals able to deal with both general and chemical education (Brazil, 1996).

Rationale

During the pre-service education, teachers already possess several ideas, conceptions and attitudes on the teaching-learning of science (Mellado, 1998) that result from many years they attended school while students, accepting or rejecting their own science teachers’ rules (Gunstone et al., 1995). Those conceptions were formed since the beginning of each teacher’s education and, according to some researchers (Aguirre et al., 1990), do not change significantly during university education. On the other hand, in a case study with two pre-service chemistry teachers followed through their methodologies, practicum experience, and student teaching internship, Veal (2004) found that while the beliefs about contents did not change, those for teaching did. In a learning situation, taking account of learners previous ideas is crucial for the design and development of the learning process. This is also valid for teachers as learners (Coenders et al., 2008). This research intends to address questions related to pre-service
teachers’ beliefs related to education, their visions on teaching and teachers, and their conceptions on the ideal chemistry curriculum and its role. The results presented in this paper are relevant for the adequate planning of the so-called “Intersection Disciplines”, which play a central role in Chemistry Teacher’s Education Programs, assisting future teachers to combine chemical-content and pedagogical knowledge.

Methods

Participants and setting

This research was conducted during a one-semester Chemistry Teaching Method discipline in the year of 2004 at the University of São Paulo (Brazil). This discipline was offered as part of an undergraduate chemistry teacher education program and was attended by twenty three students. The main goal of such discipline is related to discussion of chemistry curriculum and teaching plannings within the framework of secondary education.

Instruments and Methods of Analysis

The current study focuses on the analysis of the following material, which was produced during the course of the discipline: i) interviews; ii) proposal of an school year teaching planning and individual class plans for secondary education in Chemistry; and iii) students’ conceptions about teaching plannings, pre and post-discipline.

Interviews

Semi-structured interviews were carried out with eleven students and were structured around the following main questions: i) why did you choose to be a chemistry teacher? ii) why is it important for a secondary level student to study chemistry? iii) does the university entrance exam influence chemistry education? iv) concerning the use of laboratory work in secondary level: should it be used? Which are its main goals?

The interviews were audio-recorded, transcribed and analyzed. The analyses of the interviews were done according to the methodology proposed by Galiazzi (2003) and Galliazzi and Gonçalves (2004). Briefly, starting from the transcriptions of the interviews, selected parts were decomposed into “Significative Units”. Categories were then produced in accordance to the characteristics of the “Significative Units”. Finally, by assembling these data, interpretative texts were created. In order to position each “Significative Unit” in its respective category and to express the fraction of students that refer to each of them, tables were constructed, as proposed by Santos and Schnetzler (1996).

Teaching Plannings

For the making of the teaching plannings, students were given freedom to work according to their beliefs of an ideal chemistry curriculum for secondary school. These plannings were categorized according to different curriculum emphases, grouped into two categories: “General Education” and “Chemical Education” (Van Driel, 2005). “Chemical Education” comprises three emphases: Fundamental Chemistry (FC), Chemistry, Technology and Society (CTS) and Knowledge Development in Chemistry (KDC). “General Education” includes Career, Discipline, Product, Pedagogy, Democracy and Process. Such categories were be used to understand the curriculum emphasis that student-teachers assign to the teaching process in their plannings. In the present work, twenty three planning were analyzed.

Questionnaires

Written questionnaires were also used to probe students’ thinking about the content of a teaching planning and its purposes, before and after the discipline. Eighteen and fifteen students participated on this activity, respectively. The questionnaires were based on the following questionnaires:
Questionnaire pre-discipline: i) What is the meaning of a teaching planning?; ii) Which are the purposes of a planning?; iii) What is the goal of a planning?; iv) What is a teaching planning used for?; v) Which are the important aspects to be considered in the proposal of a teaching planning?

Questionnaire post-discipline: i) Were there any changes in your conception regarding teaching plannings?; ii) What is the meaning, the purpose and the utility of a teaching planning for secondary school?

Results

Analysis of the interviews

The analysis of the interviews led to the development of six main categories as shown in table 1. Although our intention is to analyze the transcribed interviews in a qualitative manner, we found useful to present a table that summarizes the categories of answers as well as the number of student-teachers who expressed the selected idea.

Table 1. Categories constructed based upon the interviews, significative units associated to each category and number of student-teachers who express the selected idea.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Significative Units</th>
<th>Number (N = 11)</th>
<th>Significative Units</th>
<th>Number (N = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasons and motivations for becoming a teacher</td>
<td>disappointment with Chemistry research</td>
<td>9</td>
<td>a teacher as a role model</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>social issues</td>
<td>6</td>
<td>started teaching</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>human relationships</td>
<td>5</td>
<td>teaching as a first professional choice</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>undecided about being a teacher</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teaching as a profession: is it a “mission”?</td>
<td>a mission</td>
<td>6</td>
<td>unsure</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>not a mission</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The role of teacher’s educational programs.</td>
<td>it is possible to learn to be a teacher</td>
<td>9</td>
<td>to reflect about education in chemistry</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>it is not possible to learn to be a teacher</td>
<td>1</td>
<td>to relate education and chemistry</td>
<td>5</td>
</tr>
<tr>
<td>The planning of a chemistry lesson.</td>
<td>planning is important</td>
<td>6</td>
<td>flexibility</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>organization</td>
<td>5</td>
<td>responsibility</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>content</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The importance of chemistry in secondary education.</td>
<td>chemistry as a tool to understand the world</td>
<td>10</td>
<td>argumentation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>the understanding of scientific</td>
<td>3</td>
<td>offer a professional choice</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>explanations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The role of the university entrance exam.</td>
<td>influences chemical education</td>
<td>9</td>
<td>Causes students to learn unnecessary concepts</td>
<td>5</td>
</tr>
</tbody>
</table>

The first category extracted from the interviews is related to the aspects underlying motivations to pursue a teaching career and the various specific factors that influence this decision. The professional choice to become a teacher occurs by different reasons that, in a way or another, will shape each teacher’s attitudes and beliefs about education, teaching and learning. The vast majority of students decide to become teachers, and enter teacher education program, at a later stage of their university studies. About 82% of pre-service teachers claim that their professional choice of becoming a teacher was mainly related to a disappointment with research, as expressed in the following quote:
When I got to the third year and I was a trainee in research I realized that it was not for me; I started to like education and to feel the need of a different education, more human. Then I thought... it is true, I’m going to take the chance and do the teacher’s education disciplines. (Student 1)

It is important to point out that these students were initially pursuing a Chemistry bachelor’s degree, and have been involved with chemistry research before attending teacher education courses. A large proportion of the group (46%) stated that their choice was influenced to human relationships. Research environment was described as “boring” and “lonely”, and teaching was found as a viable alternative within Chemistry. This is expressed in the following quotes:

I choose the teacher education program because I had a problem...I worked on a scientific initiation in a research lab here in the university. I liked the research but the students are alone in the lab. I’d like to be in contact with someone else, meet other people. (Student 8)

I was a PhD student, but it was boring, I couldn’t stand staying in the lab. (Student 2)

I think that the scientist job, I’m not criticizing the profession, I mean, I didn’t like to do it because I think it is too lonely, to tell you the true. I’m sorry for the pejorative word, but I think it is something autistic. (Student 11)

It seems striking in these reports a strongly stereotyped version of science shown by students from a chemistry department with strong tradition in research. It is worth noticing the naïve notions expressed by these students about scientists and scientific research that influenced their turning into teaching. Altruistic reasons, such as being able to improve society and a desire to be useful were also mentioned as important motivations for pursuing a career in teaching. Three among the interviewed students were led into teaching by positive experiences with teachers during the course of their own education. For others (27% of the group) the motivation to teach was related to their own previous teaching experiences.

In the school I studied I had a teacher that was always connected in the more interested students. He used to teach these students on Saturdays and after classes, and he was a Chemistry teacher. (Student 9)

I had a reference as a teacher, as well as with music, because I study music and music teacher is something...almost a father to me. (Student 23)

It is also interesting to notice that a minority of students have entered university with an intention of becoming a teacher. In fact, only one student claimed to have initially decided for teaching as a job, as we can observe in the speech:

When I entered in the university, during the initial classes and someone asked who wants to be a teacher, only me and another girl raising our hands. Then she quit...only me from my group, entered here decided to be a Chemistry teacher. (Student 5)

Factors limiting the pursue of teaching as a first priority may include poor working conditions, financial considerations and the low social status of teaching profession in Brazil.
The second category identified in our interviews is related to student-teachers’ understanding of the teaching professionalism, and we observed that the majority of students considered teaching as a mission rather than a profession. Student's understanding of the roles of teacher’s educational programs was also investigated in the third category. Four “significative units” were analyzed in this category. Teaching curriculum disciplines within teacher education programs combine a collection of disciplines concerned to general education, such as Didactics and Psychology, to a group of disciplines merging specific subject knowledge to pedagogical knowledge. Five students believe that one of the major roles of initial teacher training is to provide the opportunity for establishing relations between chemical and pedagogical knowledge, therefore recognizing the essential role played by the Intersection Disciplines. While most of the students understand that it is possible to learn to become a teacher, the view that this would be an impossible task was also identified in one of our students:

No, you cannot learn to be a teacher. Teacher education programs exist to offer some guidance, to show to the person that wants to be a teacher where to find information…”(Student 10)

The fourth category considered in the analysis of the interviews is related to issues that are significant to the students in the context of planning the teaching of chemistry. While the students believe in the importance of the teaching plannings, four other significative units were developed, describing particular features of chemistry plannings. Organization is considered as the main purpose of the planning. Such focus overcomes the idea of the planning as an instrument to keep record of teacher practices, and an opportunity for reflection and reconstruction of classroom practices. While planning should be regarded as a means for future teachers to assume responsibility and control for their practices and choices for the effective teaching of chemistry, we find a prevalence of the idea that planning is limited to an instrument that controls whether or not proposed goals were obtained. It is also interesting to notice that methodological issues are not significantly expressed by these students’ plannings.

The fifth and sixth categories focus on the chemistry curriculum regarding the importance of chemistry in secondary education and in the university entrance exam. The goals of chemistry education were mainly related to chemistry as a tool to understand the world, a conception which is in close resonance to the federal guidelines as suggested in the National Curriculum Parameters for Intermediate Education. The university entrance exam holds strong influences on teaching practices, and student teachers recognized that the nature of these classifying entrance examinations strongly delineates the chemistry curriculum that is in fact performed in schools. Therefore, the contents, concepts and skills probed by such exams influences didactic textbooks and teacher’s classroom practices, and cause students to learn unnecessary concepts.

Analysis of the teaching plannings

Teaching plannings produced by the student-teachers were categorized according to an instrument proposed by van Driel et al. (2005), considering general education and chemical curriculum. Tables 2 and 3 report the categories and curriculum emphasis which were considered in the student’s teaching planning according to the performed analysis. In this context, a curriculum emphasis is characterized by the objectives intended to be achieved, according to a teacher understanding.

The results indicated that the Brazilian Educational Legislation has significative influence in the conceptions of General Education of the students as can be observed by the unanimity of the Pedagogy category (mentioned in all the analyzed plannings, table 2). The educational goals of the legislation are therefore clearly reflected in the plannings of the future-teachers, although their effects in classroom activity are unlikely to occur. Democracy is also a prevalent emphasis, suggesting an intention of future teachers to consider students’ opinions and desires. This concept is also present in the educational legislation, even though it rarely reaches actual classrooms. The importance assigned to the “Process” emphasis (4 students, 17% of the group) reveals an intention to allow for the students to be responsible for their learning processes. Traditional conceptions, represented by the Career, Product and Discipline emphasis, are less frequently observed in the analyzed teaching planning’s. Therefore, for the
The investigated group of student-teachers consider that General Education should be largely centered in the students and their learning processes.

Table 2. Emphasis in general education: description of selected emphasis, examples of items and number of student-teachers who express the selected idea in their plannings.

<table>
<thead>
<tr>
<th>Emphasis</th>
<th>Examples of items</th>
<th>Number (N = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedagogy: importance of students’ personal development.</td>
<td>To educate citizens; To develop a systemic notion of knowledge; To develop critical thinking; To educate responsible and conscious citizens; General education: to develop capabilities; To prepare students for today’s globalized society; To develop abilities and competencies; To contribute to human and intellectual formation.</td>
<td>23</td>
</tr>
<tr>
<td>Democracy: values students’ opinions and desires.</td>
<td>To consider each student’s different ideas; To account for cognitive levels; To allow for the students to ask questions, raise commentaries and complaints; Freedom of thoughts and ethics with constant dialogue.</td>
<td>9</td>
</tr>
<tr>
<td>Process: importance of the learning process.</td>
<td>To educate students active in learning process; To evolve from concrete to formal levels; To develop cognitive skills.</td>
<td>4</td>
</tr>
<tr>
<td>Career: education serves to prepare students for a future career.</td>
<td>To prepare students for further education and to become professionals; To develop the capacity of using the different technologies in each field of work.</td>
<td>4</td>
</tr>
<tr>
<td>Product: emphasizes achievement.</td>
<td>To continue education; To prepare for the University entrance exam; To acquire basic knowledge preparing for further education.</td>
<td>4</td>
</tr>
<tr>
<td>Discipline: focuses on obedience, order and the will to work.</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3. Emphasis in chemical curriculum: description of selected emphasis and number of student-teachers who express the selected idea in their plannings.

<table>
<thead>
<tr>
<th>Chemical Curriculum</th>
<th>Number (N = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Chemistry (FC): focuses on theoretical notions that will provide an understanding of the natural world.</td>
<td>17</td>
</tr>
<tr>
<td>Chemistry, Technology and Society (CTS): emphasizes technological and societal issues, and focuses on the learning to communicate and make decisions about societal issues involving chemical aspects.</td>
<td>15</td>
</tr>
<tr>
<td>Knowledge Development in Chemistry (KDC): related to the learning of chemistry as a constantly developing knowledge.</td>
<td>6</td>
</tr>
</tbody>
</table>
Results obtained specifically with respect to teacher’s beliefs concerning Chemical Curriculum are illustrated in Table 3. The investigated group of student-teachers believes that the main focus should lie within Fundamental Chemistry (17 teaching plannings, 74 %); however almost the same importance is given to the emphasis of Chemistry related to Technology and Society (15 plannings, 65 %). It has been proposed by van Driel (2005) that high scores on the Fundamental Chemistry emphasis can be associated to content-centered educational orientation, while high scores on Chemistry, Technology and Society indicate a learner-centered orientation. These two views were dominantly present among the investigated teachers, suggesting that they equally rely upon both, subject matter and learner-centered orientations.

Ideas on teaching planning: before and after

We also intend to explore to what extent do the activities held during the Chemistry Teaching Method discipline influence student’s ideas and conceptions on teaching planning. This was carried out by the analysis of written questionnaires answered by the student-teachers at the beginning and at the end of the discipline. The main findings are summarized in table 4.

Table 4. Conceptions regarding the main purposes and roles of teaching plannings expressed by the student-teachers before and after attending the discipline.

<table>
<thead>
<tr>
<th>Features</th>
<th>Student-teachers</th>
<th>Before (N = 18)</th>
<th>After (N = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emphasis in organization</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than organization</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Opportunity for reflection</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

The idea initially held by the group of pre-service teachers can be described as a consensus that a teaching planning is strictly related to organization (Table 4). The final conceptions reveal a more complete and articulated understanding of the purposes and uses of the teaching plannings. Table 4 shows changes in the students’ ideas of teaching planning caused by the discipline, while the trends in the data demonstrates that the importance assigned to flexibility and opportunity for reflection and replanning increases in a significative way across the semester.

Conclusions and Implications

In this work, chemistry student-teachers’ beliefs on education, learning processes and curriculum were investigated in a context of educational reform.

Interviews were used to explore the prevailing conceptions and attitudes of the student-teachers on the teaching and learning of science, their understanding of the teaching profession and the role of teacher educational programs. Analyses of the interviews reveal that students’ motivations for pursuing a teaching career are strongly related to disappointment with chemistry research. Results also suggest a convergence of the investigated teacher’s ideas as regard to important aspects of chemical education and curriculum for secondary school (such as the importance of chemistry and the role of the university entrance exam). This homogeneity reflects the group recognition of the education legislation and prescribed curriculum and of the pressing needs of the different assessment practices to which students, and therefore, teachers are submitted.
Teaching plannings for secondary school produced by the student-teachers were categorized considering two perspectives: general education and chemical curriculum. Analysis of curriculum emphasis within these perspectives allow for the characterization of the teachers understanding of the main objectives to be achieved in both domains. The obtained results reveal strong influence from the Brazilian Educational Legislation in the teachers’ conceptions of Chemistry Curriculum. Student-teachers prevailing conceptions within general education domain shows strong emphasis in aspects related to the importance of students’ personal development, the values students’ opinions and desires and importance of the learning process. Traditional conceptions - represented by career, product and discipline emphasis - are less frequently expressed. Therefore, the investigated group of student-teachers considers that general education should be largely centered in the students and their learning processes. Results obtained specifically with respect to student-teacher’s beliefs concerning chemical curriculum suggests that the comparable importance is given to chemical content and technological and societal issues. These two views - related to Fundamental Chemistry and Chemistry, Technology and Society - were expressed among the investigated plannings, suggesting that this group of student-teachers hold to a large extent both subject-matter and learner centered oriented beliefs.

Acknowledgements

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References


A Mixed Methods Approach to Characterise the Beliefs on Science Teaching and Learning of Freshman Science Student Teachers from Different Science Teaching Domains

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Abstract

This paper integrates data from four different research studies, which are both qualitative and quantitative in nature. The studies describe beliefs of science student teachers from four different domains of science teaching (secondary biology, chemistry and physics, as well as primary science). One study is based on drawings from science student teachers about teaching situations which led by Grounded Theory towards three qualitative scales about beliefs on classroom organisation, teaching objectives, and epistemological beliefs. Three quantitative studies gave insight into student teachers’ curricular beliefs, beliefs about the nature of science, and about the student- and teacher-centeredness of science teaching. In this paper a design is described to integrate all these data within a mixed methods approach with the aim to describe a broad and triangulated picture about the science student teachers’ beliefs on teaching and learning science. Clear overall tendencies between the sub-groups were found when recapitulating all the data from the four studies simultaneously. The results suggest that beginning chemistry and, even more pronouncedly, physics student teachers profess quite traditional beliefs about teaching and learning science. Biology and primary science student teachers express beliefs towards teaching and learning in their subjects more in line with modern educational theory.

Introduction

Pajares (1992) defined beliefs as being fundamentally about something. Nevertheless, teachers’ beliefs and knowledge about teaching and learning are often tacit (Shulman, 1988) and tenacious. Bandura (1986) stated that beliefs represent the best indicator of why one person behaves, acts and makes decisions in a certain way. Every science teacher has his or her own beliefs about teaching and learning which influence teaching strategies and behaviors (Hewson & Kerby, 1993). Koballa, Gräber, Coleman and Kemp (2000) concluded that beliefs influence all kind of interactions between teachers and pupils and also suggested that teachers’ beliefs about teaching and learning always include aspects of beliefs exclusive to their chosen discipline or subject. Pajares review from 1992 illustrated the notion that beliefs play a critical role in defining behavior and in organizing knowledge and information. Similarly, one can assume that student teachers’ beliefs affect both their learning and their understanding of teaching through every step of their teacher education. This position was supported by Fischler (2000), who evaluated the influence of student teachers’ beliefs on their practical actions in class when asked to collect initial teaching experiences during their school internships. An understanding of student teachers’ beliefs is and remains elementary for improving their professional development (Pajares, 1992).
In line with Pajares (1992), we see ‘teachers’ beliefs’ as an inclusive construct which covers any mental predisposition a teacher or student teacher holds and which affects his behaviour in class (Markic, Valanides & Eilks, 2006; Markic, Eilks & Valanides, 2008; Markic, 2008). Those beliefs stem from personal experience, knowledge or social background. Some research on science student teachers’ beliefs and the differences between primary school science and secondary school biology, chemistry and physics is already available (see e.g. in Markic & Eilks, 2008).

Tsai (2002) categorized student teachers’ beliefs about teaching, learning, and science as traditional, process-oriented, or constructivist. In his study, the majority of 37 Taiwanese science teachers held traditional beliefs. More importantly, over half of these student teachers has beliefs about teaching, learning and science that were closely aligned. In 2006, Tsai performed an evaluation of the relationship between the different beliefs. He concluded that "adequate coherence" existed between the subjects’ scientific epistemological beliefs and their classroom teaching (Tsai, 2006).

Several researchers concentrated on special groups of (student) teachers. Aguirre, Haggerty and Linder (1990) showed that science student teachers often conceptualize teaching as ‘a knowledge transfer’ or ‘an influence or change in understanding’. They view learning as ‘an intake of knowledge,’ ‘an attempt to make sense in terms of existing understanding’ or ‘an affective response’. In Germany, Fischler (1999; 2000) evaluated physics student teachers’ beliefs in terms of thinking about their own physics classes at school. The usual response was a very dominant teacher, very passive pupils, and bad images of physics. Koballa et al. (2000) described German chemistry student teachers’ beliefs as reproductive rather than constructive. Furthermore, they stated that for chemistry beliefs about teaching and learning were very similar, regardless of whether students were teacher-trainees or never intended to become teachers at all. Nevertheless, such belief were not fully developed or clearly reflected in many cases. Niehaus and Vogt (2005) performed a study with biology teachers and student teachers in Germany. They concluded that there are three types of biology (student) teachers. They distinguished between pedagogical-innovative, scientific-innovative, and scientific-conventional types. This study showed that biology (student) teachers’ beliefs are a mosaic of different categories and cover a wide range without showing any clear tendency towards more conventional or more modern beliefs.

A study by Cronin-Jones (1991) showed that the most important student outcomes (according to teachers) are factual knowledge of their pupils, middle-grade students learning through repeated drill and practice and, finally, middle school students requiring a great deal of direction. While evaluating teachers’ curricular beliefs Van Driel, Bulte and Verloop (2005; 2006) found that Dutch chemistry teachers most supported a belief that their main goal was to introduce students to the fundamental concepts and skills within chemistry, so as to prepare them for future training. In their study on beliefs of teaching goals, Furiò, Vilches, Guisasola and Romo (2002) also showed that most Spanish teachers gave more weight to goals focusing on the structure and methods of science. Much less support was given to scientific literacy.

Murcia and Schibeci (1999) studied the beliefs of primary science student teachers. They found that the identified concepts contained several elements which clearly did not correspond with a developed understanding of Nature of Science. The respondents displayed a naïve and unclear understanding of the scientific method and a poorly developed understanding of scientific theory. Aguirre et al. (1990) also showed that most pre-service teachers hold only a naïve concept of the Nature of Science. They believe that the function of science is to discover the ‘laws of nature’.
Sample

The sample consists of freshman science student teachers from four different German universities. The sample are 44 chemistry, 36 physics and 48 biology student teachers aiming to become a secondary science teacher (grades 5-13), plus 52 primary (grades 1-4) science student teachers. Data collection took place within the first two weeks of their various university teacher education programs, which was to nearly all of them the start of their entire higher education. Thus, all student teachers did not have had any university courses prior to this study. This data collection period was specifically chosen because it precludes any influences on the beginning students from either university coursework or professors.

The selection of this data sample was not representative in statistical means. Nevertheless, most of the German student teachers have similar formal qualifications for university access. Also the distribution of age and gender was very prototypical for similar groups of student teachers in the respective subjects. Using this point-of-view as a springboard, there is no sound reason to assume that these student teachers are special in any respect. There can be no logical assumption that the results would differ notably by sampling a new test group from other German universities involved in science teacher education. Through selection of the sample, this study remains a case study with a sound base of information, allowing a careful hypothesis about student teachers’ beliefs in the sciences all over Germany.

Methods

Different instruments, both qualitative and quantitative, were used to generate the data base for the here presented mixed methods study. The different dimensions evaluated by the various tools are separate, independent beliefs. As a consequence, the beliefs were first analyzed individually (see also Törner, 1996). For propose of this study an integration of qualitative and quantitative data as described by Mayring and Alexandrowicz’ (2004) definition has been used. Priority is given equally to the qualitative and quantitative approaches. The integration is performed not only during data collection, but during data analysis and data interpretation as well. The theoretical perspective is implicit. Starting with the idea of five-step scales developed and used in the qualitative study, a decision was made to develop similar scales for the quantitative data as well. Using mixed methods (Tashakkori & Teddlie, 2003), the integration of both quantitative and qualitative data were interpreted in such a way that the data from all four studies could be represented through similar five-step scales.

In the qualitative part of the study, the participants were instructed to draw themselves as science teachers of their respective subject in a typical classroom situation and to answer four open questions. This idea relates to the ‘Draw-A-Science-Teacher-Test Checklist’ (DASTT-C) (Thomas, Pedersen & Finson, 2001) supplemented with questions about teaching objectives, and prior activities. Development of the data analysis pattern using Grounded Theory (GT) is described in Markic, Eilks and Valanides (2008). The core category based on GT is the range between the predominance of more traditional and more modern teaching orientation in line with educational theory. Three 5-step scales were developed using GT focussing on 1) Beliefs about Classroom Organisation, 2) Beliefs about Teaching Objectives and 3) Epistemological Beliefs. The validity of the data was achieved through independent rating and searching for inter-subjective agreement (Swanborn, 1996). The evaluation pattern developed using Grounded Theory (Glaser & Strauss, 1967) does not present a linear scale. Keeping this in mind, some statistical steps must be performed to integrate the qualitative and quantitative data. In this context, we have to be aware that Likert-scales are not read by the sample as being linear in all cases. Results of the study are described in Markic and Eilks (2008).

The quantitative part of the study consisted of two Likert-questionnaires and a reinterpretation of a part of the qualitative data. One questionnaire focused on student teachers’ curriculum emphases beliefs (Van Driel et al., 2006). The evaluation here used only covers the two Curriculum Emphases Fundamental Science (FS) and Science, Technology and Society (STS). In line with the actual debate about modern science education and the new German National Science Standards (Klieme & Steinert, 2004), the curriculum emphasis Fundamental Science (FS) is considered
to represent more traditional beliefs, whereas *Science, Technology and Society* (STS) is seen as being more modern (see also Van Driel et al., 2005). Freshman science student teachers’ mean scores were subtracted: *Science, Technology and Society* mean score minus *Fundamental Science* mean score. A five-step scale showing the relative frequency for the differences between the mean scores was calculated by grouping the sample based on empirical quantiles (Koenker & Bassett, 1978). 20%-quantiles were used in order to achieve a five-step scale. The scale is based on describing how scientific knowledge and Science learning interact with technology and society. The scale for Beliefs about the Value of Learned Scientific Knowledge has to do with why one should learn science: just to possess scientific knowledge or to use such to (inter)act within society.

The second questionnaire evaluated student teachers’ beliefs about the nature of school science (Chen, Taylor & Aldridge, 1997). The relative frequencies for the mean scores for the whole sample were calculated. A five-step scale was developed by grouping the sample based on empirical quantiles. The five steps represent a group of mean scores from the dimension Beliefs about the Nature of School Science. The new scale for Beliefs about the Nature of School Science Knowledge is a range showing student teachers’ level of understanding of knowledge and inquiry within school science. This range represents the spectrum between two possible extremes: scientific knowledge as memorized, unchangeable facts and knowledge as tentative and something created within a socio-historic context.

A third quantitative scale was developed by the checklist of DASTT-C as originally described by Thomas et al. (2001): Beliefs about Teaching Style. Also here a five-step scale was developed. Scores for each freshman student teacher were rated. The relative frequency for the scores was then calculated. A five-step scale was developed, also based on the idea of grouping on the basis of empirical quantiles.

A grouping on the basis of empirical quantiles was again applied to finally integrate all the data and to allocate the sub-groups within the whole population. The mean scores for each of the six five-step scales were calculated. Relative frequencies for the twenty-four mean scores were calculated and grouping based on empirical quantiles of the whole population was used. A new five-step scale was developed. For better visual representation of the data, every number was given a shade of gray: the lighter the colour, the more modern are the beliefs. The transformation from the mean scores and scores from the quantitative questionnaires was performed. All six scales were interpreted as a spectrum between more traditional and more modern beliefs with regards to educational theory and research evidence as discussed in Table 1.

**Table 1: An overview of the six scales within the mixed methods design**

<table>
<thead>
<tr>
<th>Belief about Classroom Organisation</th>
<th>Traditional view</th>
<th>Modern view</th>
</tr>
</thead>
<tbody>
<tr>
<td>The classroom activities are mostly teacher-centred, directed, controlled and dominated by the teacher.</td>
<td>-2, -1, 0, 1, 2</td>
<td>Classes are dominated by students’ activity and students are able to choose and control their activities.</td>
</tr>
<tr>
<td>Belief about Teaching Objectives</td>
<td>The focus of science teaching is more or less exclusively focused on content learning.</td>
<td>-2, -1, 0, 1, 2</td>
</tr>
<tr>
<td>Epistemological Beliefs</td>
<td>Learning is passive, directed and controlled by dissemination of knowledge.</td>
<td>-2, -1, 0, 1, 2</td>
</tr>
<tr>
<td>Belief about Teaching Style</td>
<td>Teacher-centred. Teacher lectures and students watch and listen.</td>
<td>-2, -1, 0, 1, 2</td>
</tr>
<tr>
<td>Beliefs about the Value of Learned Scientific Knowledge</td>
<td>Knowledge is value-free.</td>
<td>-2, -1, 0, 1, 2</td>
</tr>
<tr>
<td>Beliefs about the Nature of School Science Knowledge</td>
<td>Knowledge as established, unchangeable facts (objectivistic view).</td>
<td>-2, -1, 0, 1, 2</td>
</tr>
</tbody>
</table>
Results

Table 2 presents the allocation of the subgroups within each scale and with respect to whether more traditional or more modern beliefs are predominant in each of the sub-groups. The first three categories stem from the qualitative analysis and last three from the quantitative. The column representing the freshman physics student teachers group is extremely dark, with the neighboring chemistry column only a shade lighter. This reflects the fact that the two groups dominantly scored between -2 and -1, respectively. The further we go to the left side of Table 2, the lighter the color values become.

Table 2: Presentation of the data according to mixed method (The lighter the colour, the more modern are the beliefs in a range from -2 to +2)

| Beliefs about the Classroom Organisation | Physics | Chemistry | Biology | Primary Science |
| Beliefs about Teaching Objectives | | | | |
| Epistemological Beliefs | | | | |
| Beliefs about Teaching Style | | | | |
| Beliefs about the Value of Learning Scientific Knowledge | | | | |
| Beliefs about Nature of School Science Knowledge | | | | |

In detail we can see that in general:

- Freshman physics student teachers hold very traditional beliefs. Their scales for Beliefs about the Value of Learned Scientific Knowledge and Beliefs about the Nature of School Scientific Knowledge were scored with a value of 0. In all other scales, the physics student teachers are the most traditional.

- Freshman chemistry student teachers also lean towards more traditional beliefs. They achieved scores of -1 in all of the categories except Beliefs about the Value of Learned Scientific Knowledge.

- Freshman biology student teachers scored on average +1 (concerning classroom organisation they scored a +2). In the categories Beliefs about the Value of Learned Scientific Knowledge and Beliefs about the Nature of School Scientific Knowledge they obtained a score of 0.

- Freshman primary science student teachers have the most modern beliefs of all the groups. They achieved a score of +2 in 4 out of the 6 categories.

Conclusions and Implications

The results achieved through integration of the qualitative and quantitative data were able to provide a more holistic picture of sample of student teachers than those presented in Markic and Eilks (2008 or 2009). Nevertheless, a lot of details of the individual studies and the overall consideration were supported by integration of the data, including the overall impressions gotten when observing the studies individually.

Student teachers of physics from this sample have the most traditional beliefs in most of the qualitative and quantitative categories. Freshman chemistry student teachers also profess quite traditional beliefs when starting their teacher training program, although not as strongly as their physics counterparts. At the other end of the spectrum, student teachers of biology were associated with more modern beliefs about science teaching and learning. This trend became even more obvious when analyzing the group of future primary science student teachers.
Interpretation of the data focused on many different aspects of the subjects’ beliefs and was based on completely different kinds of data and evaluation methods.

Furthermore, there are three pairs of each a qualitative and a quantitative category with some relationship (Beliefs about Classroom Organisation and Beliefs about Teaching Style; Beliefs about Teaching Objectives and Beliefs about the Value of Learning Scientific Knowledge; Epistemological Beliefs and Beliefs about the Nature of School Scientific Knowledge). These relationships can provide us more evidence when applied in the sense of triangulation. Using triangulation, the data in one category was partially supported by one of the other categories. However, the categories overlap each other, but not fully, because they are not identical in focus. The categories can be seen as supplementing one other. Through combination of the different scales we can reveal more information than with only one of the perspectives singly.

Finally, interpreting the data sets together guided us to a deeper understanding of and more reflection upon each of the categories itself. All three qualitative categories (Beliefs about Classroom Organization, Beliefs about Teaching Objectives and Epistemological Beliefs) express much more then the quantitative categories (Beliefs about the Teaching Style, Beliefs about the Value of Learning Scientific Knowledge and Beliefs about the Nature of School Science Knowledge), however, this might be a weaker definition. Furthermore, we should be conscious that only partially similar beliefs were described by the qualitative and quantitative data. The qualitative categories simply cast a broader net than their quantitative counterparts.

By integrating the four studies, the similarity of the tendencies in the beliefs among the different categories and the massive differences between the four groups of student teachers, lead to the assumption that we are here dealing with belief systems (Rokeach, 1968). A belief system is harder to change than individual and unconnected beliefs. The appearance of such a kind of belief system asks for better reflection and deeper contention with the beliefs described above and suggests a more systemic approach for their change and development. The existence of such belief system also implies to be aware that an attempt to change a specific belief of a student teacher could potentially influence his/her other beliefs.

What can we obtain from this overall consideration? The evaluation of student teachers’ beliefs is very important for better understanding their learning during teacher training (Fischler, 1999). Therefore, an evaluation of student teachers’ beliefs should be part of their university education. This would make both science teachers and science educators explicitly aware of such beliefs and their consequences. Reflection upon and discussion of explicit beliefs can be helpful in fostering conceptual changes in student teachers and in steering them from more traditional towards more modern beliefs. This should be connected to a reflection of own experiences as a learner and teacher with traditional and modern scenarios of learning and instruction.

Science education should also concern itself with the question of whether or not student teachers’ initial beliefs act as a springboard for career choice when choosing a school subject or level to teach. It is a plausible hypothesis that, if all potential science teachers have beliefs similar to those found in this study, it should come as no surprise that the numbers of chemistry and physics student teachers are so low when compared to biology or primary science teacher candidates. Moreover, two serious questions remain:

(i) Why, if such stereotypical beliefs and opinions are so dominant among physics and chemistry student teachers, do they choose their subject in the first place?
(ii) What type and quality of student teachers do universities and schools get for these two subjects?

We cannot answer this question with this study, but the data should motivate future researchers to look more deeply into these questions (see also Markic, Valanides & Eilks, 2006; Markie & Eilks, 2008; 2009).
References


TEACHERS’ BELIEFS ABOUT MAKING PHYSICS ENGAGING AND COMPREHENSIBLE FOR SECONDARY STUDENTS IN THE NETHERLANDS

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Abstract

This paper discusses the results of a small-scale explorative interview study with four physics teachers of two different Dutch secondary schools by focusing on their beliefs about making physics engaging and comprehensible for secondary students in The Netherlands. The present study is part of a long-term research project (2007-2011) on the content and structure of physics teachers’ belief systems about teaching and learning physics. Results of this empirical study seem to indicate that physics teachers are mainly focused at teaching and learning scientific concepts; skills and values serve as means to achieve this goal. Furthermore, teachers arrange different types of cognitive, affective, and regulative learning activities and these seem to be related to teachers’ own preferences for particular parts of the subject matter (e.g., the logical and coherent structure of formalized knowledge and the challenge of problem solving and modelling natural phenomena) and to complicating factors in teaching and learning physical concepts (e.g., students’ problems with abstractions, students’ lack of important mathematical and problem solving skills, and students’ lack of motivation).

Introduction

The image of secondary science education has been problematic for the past decades. All over Europe the interest in science among young students seems to be irrevocably waning (Rocard, et al., 2007). Although students are interested in science itself (Osborne, Simon, & Collins, 2003) and are convinced of the importance of science and technology for society (Matthews, 2007), many of them lose interest due to the way science is taught. Students often perceive science education to be limited because most topics of the science curriculum are chosen by the teacher (Rocard, et al., 2007). Moreover, students associate science subjects (e.g., physics) with such image aspects as masculinity and difficulty (Kessels, Rau, & Hannover, 2006). Due to the fact that students’ enjoyment of science subjects is highly affected by teacher behaviour (Darby, 2005), there is an increasing attention for the role of science teachers (Osborne, et al., 2003).

The way teachers teach their subject is, amongst other things, related to their beliefs. In particular, beliefs about teaching and learning in general, epistemological beliefs, and domain-specific beliefs are deemed important in this respect (Richardson, 1996). In the domain of science education, some studies have been conducted on teachers’ beliefs about the goals of teaching science and the characteristics of instruction (Magnusson, Krajik, & Borko, 1999), whereas others focused on teachers’ personal epistemologies about knowing and their conceptions of the
nature of science (Lederman, 1992). So far, still little is known about the relations between teachers’ general educational beliefs, epistemological beliefs, and domain-specific beliefs about teaching and learning science. The main goal of our research project is to obtain a better understanding of the content and structure of science teachers’ belief systems about teaching and learning science; we particularly focus on the subject of physics. In this paper, we narrow the scope down by exploring physics teachers’ beliefs about making their subject engaging and comprehensible for secondary students in the Netherlands.

**Rationale**

Research on Teacher Beliefs

As mentioned before, the practice of teaching is influenced by teacher beliefs. According to Pajares (1992) these beliefs play a critical role both in organizing knowledge and information, and in defining and understanding behaviour. Moreover, beliefs are organized into a system: knowledge and beliefs are inextricably intertwined and beliefs are prioritized according to their relations with or connections to other beliefs or other affective and cognitive structures. Literature shows that the relationship between teachers’ beliefs and their teaching practice is not straightforward (e.g., Thompson, 1992). For instance, in the domain of science education some studies found very coherent relationships between beliefs and practice, especially in studies of experienced science teachers (e.g., Brickhouse, 1990). Others, however, reported discrepancies between teachers’ expressed beliefs and their observed classroom practice (e.g., Briscoe, 1991). In order to obtain more understanding of science teachers’ belief systems about teaching and learning science, we conducted a small-scale explorative study on physics teachers’ beliefs about making physics engaging and comprehensible for secondary students in the Netherlands.

The Content of Science Education: Conceptual Knowledge, Skills, and Values

Obviously, teachers’ beliefs about how to make the subject matter more accessible for students are to some extent related to the aims and goals of the science curriculum. However, according to Osborne and Dillon (2008), most school science curricula attempt to serve two goals instead of one goal, namely: (1) preparing a minority of students to be the next generation of scientists and (2) educating in and about science (since the majority of students will strive for non-scientific careers). Many teachers feel a tension in trying to achieve both of these goals at the same time since the understanding of the major ideas of science requires a relatively high level of science education (namely teaching the fundamentals of science and developing a sense of its explanatory coherence). In addition, Schulz (2009) argues that science education is plagued by a fundamental problem: the lack of a guiding ‘metatheory’ of education. Until now, three chief objectives or rationales have been operative in education possibly undermining each others’ intended aims. As a consequence, the process of determining the goals and content of the science curriculum is often mixed up if not dominated by the longstanding discussion “whether to teach science for (1) intellectual development (knowledge), or (2) for individual fulfilment (character), or (3) for socio-economic benefit” (Schulz, 2009, p. 232).

The content of science is characterized by the interplay between scientific concepts, skills and values. Science exhibits itself as “an accumulated body of knowledge, but especially as a knowledge generating and techno-social enterprise” (Schulz, 2009, p. 231) enabling students to develop and cultivate creativity and critical thinking skills. Scientific knowledge deals with imagination, experiments, practical and theoretical know-how, discipline, and models (as controlled thought experiments) (Ogborn, 2008). In addition, various skills are needed and used, such as analytical skills (e.g., analyzing and modelling a physical process, logically and systematically pursuing a line of thought), theoretical skills (e.g., applying theory and theoretical concepts to a broad spectrum of problems), experimental skills (e.g., hypothesizing, gathering data, and logical data-based decision-making), and problem-solving skills (e.g., creative thinking skills, mathematical skills, practical, and technical skills) (Talisayon, 2008). Furthermore, science can be appraised in different ways by paying attention to different scientific values (e.g., measurable accuracy curiosity, and fascination). However, according to Talisayon (2008), many science teachers consider values and skills
as means to learn scientific concepts. She argues that concepts, skills and values are equally important particularly because they are transferable to many areas in life. Therefore, she recommends a shift of focus in order to place more emphasis on skills and values in the practice of teaching science.

Cognitive, Affective, and Regulative Learning Activities

Teaching is an idiosyncratic profession. Teachers have to decide what learning and thinking activities are to be incorporated in their lessons and these decisions are influenced by their personality and personal beliefs. In regulating students’ learning processes, teachers can play different roles. Vermunt and Verloop (1999) list out six different teacher roles, namely: the teacher as diagnostician, challenger, model learner, activator, monitor, and evaluator. Each role is characterized by the use of different teaching strategies and the arrangement of various types of learning activities. According to Vermunt and Verloop (1999), a distinction can be made between cognitive, affective, and regulative learning activities: Cognitive learning activities are those thinking activities that aim at processing subject matter and “that lead directly to learning outcomes in terms of changes in students’ knowledge base” (p. 259). Affective learning activities are employed to cope with emotions that arise during learning and aim at impairing or fostering the progress of the learning process. Regulative learning activities are those thinking activities that are used to decide on learning contents, to exert control over the cognitive and affective activities, and to steer the course and outcomes of students’ learning. Teachers could draw on these various categories of learning activities in order to make the subject matter more engaging and/or comprehensible for their students.

Aim of the Study – General Research Question

The purpose of the present study is to explore physics teachers’ beliefs about teaching and learning physics. General research question is: How to make physics engaging and comprehensible for secondary students? In finding an answer to this question, we explore the various learning activities that are arranged by physics teachers; we pay attention both to the different types of learning activities (cognitive, affective, and regulative) and to a teacher’s focus on scientific concepts, skills and/or values. Furthermore, we compare the various learning activities with personal characteristics of the teacher, such as gender, years of teaching experience, and a teacher’s opinion about what makes the subject matter of physics engaging and difficult.

Methods

The present study was conducted within a long-term research project (2007-2011) in the Netherlands on the content and structure of teachers’ belief systems about teaching and learning physics. In the process of preparing a large-scale quantitative survey study, we decided to conduct a small-scale semi-structured interview study with physics teacher trainers and physics teachers in January 2009. This paper discusses the results of the latter small-scale qualitative study; we focus on the group of physics teachers and analyse their beliefs about how to make physics education engaging and comprehensible for secondary students.

Sample

We selected four teachers by purposeful sampling based on the criteria that each teacher should have been teaching physics to secondary students for at least five years. Furthermore, the sample should include teachers teaching the middle and the higher level of secondary education (this is called havo and vwo in the Dutch educational system). This resulted in a sample of one female and three male physics teachers being appointed at two Christian schools located in the province of Zeeland, the southern part of the Netherlands.
Development of the Interview Scheme

In order to investigate the breadth of the learning activities that teachers arranged in their teaching practices, we developed an interview scheme with a range of questions about the knowledge of physics (e.g., the nature of physics and the content and goals of the curriculum), strategies to teach the subject matter, the role and characteristics of the learner, the content and focus of assessment, and characteristics of the environment and/or community that enhances teaching and learning physics. The general framework about How People Learn of Bransford and colleagues (2005) functioned as a starting point in formulating questions about different aspects of the practice of teaching. Moreover, we asked some general questions about the teacher's tasks and activities at school, his or her priorities and main educational goals, possible factors that complicate teaching and learning physics, and the teacher’s preferences concerning the subject matter. After piloting the interview scheme with four other physics teachers (all of them are teaching at secondary schools in the Netherlands) in November 2008, we composed and determined a final list of interview questions.

Duration and Content of the Semi-structured Interviews

All four interviews were conducted in the same week, with a total duration ranging from 47 to 83 minutes. The sequence of the questions was semi-structured and depended partly on the interview scheme and on the topics the teacher was talking about. All interviews were audio taped and subsequently fully transcribed.

Analysis

Data were analysed in an iterative process characterized by two main phases: (1) a broad content analysis of a teacher’s opinion about what makes (teaching and learning) the subject matter of physics engaging and difficult and what learning activities are arranged by him or her in order to make the subject engaging and comprehensible, and (2) an in-depth analysis of the arranged learning activities of each teacher. During the first phase we coded the transcripts of all four interviews and listed out what aspects are, according to the teachers, accountable for making the subject engaging and difficult. Furthermore, we made a list of learning activities that were arranged by each teacher to make the subject engaging and comprehensible. The second phase comprised an analysis of each singular learning activity focusing on (a) the aim of that particular activity, namely: the intention to learn and/or emphasize scientific concepts, skills or values, and (b) the type/nature of that activity by using the categorization of learning activities of Vermunt and Verloop (1999) as a leading framework. An illustration of the second phase of data analysis can be found in Table 1; we give a few examples of learning activities arranged by the teachers together with the aim of that activity and the type of activity.

Table 1. Illustration of the second phase of data analysis.

<table>
<thead>
<tr>
<th>Learning activity arranged by a teacher</th>
<th>Aim of the activity</th>
<th>Type of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching formulas: Writing down the deduction of formulas in a systematically way and paying attention to each singular step of deduction by focusing on the reasoning behind/the background of this step.</td>
<td>Learning a Scientific Concept</td>
<td>Cognitive - Analyzing</td>
</tr>
<tr>
<td>Asking students how to solve a particular problem by forcing students to think aloud and asking students to tell the sequential steps of their strategy to solve this problem.</td>
<td>Learning Skills (Problem Solving)</td>
<td>Regulative – Monitoring/ Testing/ Diagnosing</td>
</tr>
<tr>
<td>Showing the use(fullness) of physics for students’ future lives by paying attention to the application of physical knowledge in various (non-scientific) jobs.</td>
<td>Emphasizing a Value</td>
<td>Cognitive – Concretizing/ Applying</td>
</tr>
<tr>
<td>Consequently taking your departure from the idea that students are able to learn the subject matter: assuring students again and again that they are able to learn the subject matter</td>
<td>Learning a Scientific Concept</td>
<td>Affective – Dealing with emotions</td>
</tr>
</tbody>
</table>
Results

Personal Characteristics of the Teachers

We asked the teachers to fill out a short questionnaire about their age, teaching experience, and training/education. The results are presented in Table 2.

Table 2. Overview of Personal Characteristics of the Teachers.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Gender</th>
<th>Age</th>
<th>Teaching experience</th>
<th>Training/Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>37 years</td>
<td>8 years</td>
<td>Applied Physics (university of technology)</td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
<td>57 years</td>
<td>33 years</td>
<td>Physics and Chemistry (teacher training secondary education – lower grades)</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>35 years</td>
<td>15 years</td>
<td>Physics (teacher training secondary education – lower and higher grades)</td>
</tr>
<tr>
<td>4</td>
<td>Male</td>
<td>53 years</td>
<td>25 years</td>
<td>Physics (university) and Chemistry (partly university, teacher training secondary education – lower grades)</td>
</tr>
</tbody>
</table>

Engaging and Difficult aspects of the Subject of Physics

During the interviews, we asked the teachers’ opinion about engaging and difficult aspects of teaching and learning physics. With reference to the engaging part, all teachers referred to subject matter-related aspects and three out of four teachers explicitly pointed at aspects of the process of teaching physics. Concerning the difficulties in teaching and learning physics, all teachers talked about three different types of complicating factors, namely subject-matter related aspects, students’ characteristics and school-related aspects. We shall now briefly discuss the results of each teacher.

Teacher 1

According to teacher 1, the engaging and interesting part of physics is related to the logical and systematic construction of physical knowledge. Physics is concerned with finding and modeling the various laws of nature. The logical structure of physical knowledge makes it possible to reason about natural phenomena by analyzing and applying formulas, computing, predicting, and testing the progress of physical processes and natural phenomena.

Difficulties in teaching and learning the subject matter of physics are primarily related to the fact that formalized knowledge consists of abstractions. Various scientific concepts (e.g., energy and forces) require a high level of abstract thinking due to the fact that it is difficult to concretize and demonstrate the subject matter by giving appropriate examples of applications (for instance in students’ daily lives) or by arranging illustrating experiments, practicals/lab sessions and hands-on-activities. As a consequence, students often complain about a lack of relevance of the subject matter (e.g., they don’t see the importance of the reasoning behind the deduction of formulas). With reference to students’ characteristics, most students are lacking important mathematical skills, such as methods to calculate the (surface) area and/or the tangent line of something or applying formulas in assignments. Furthermore, students differ in competence, interest, discipline, motivation, and responsibility towards their own task. For instance, some students don’t ask questions in order to understand the subject matter. When it comes to school-related aspects, the most complicating factor is a chronic lack of time. Forced by a shortage of courses in the weekly schedule, teachers only select basic scientific concepts and aspects to teach to students. Another problem is the fact that the curriculum of mathematics doesn’t connect with the curriculum of physics, which results in a lack of important skills amongst students. Finally, it is sometimes difficult to set up group work due to a fixed position of tables and chairs in some classrooms.
Teacher 2

In line with the first teacher, teacher 2 considers physics engaging because of the logical and systematic nature of natural phenomena. Laws of nature are empirically found, constructed and tested with experiments, consequently leading to a firm body of formalized knowledge. In addition, dealing with the subject matter of physics requires problem solving and creative thinking skills due to the fact that nature hardly repeats itself in exactly the same way. Furthermore, applications of physics can be found in every detail of our daily life, such as artifacts (e.g., the mechanism of many doorknobs is based on leverage), the production and processing of fabrics and materials, and the media reporting about scientific research and technological inventions. As a result, the subject of physics can be taught from multiple perspectives but particularly from a historical one, for instance by focusing on historic inventions (e.g., the steam engine and the use of X-ray in health care) and the origin of terminology (e.g., terms as Joule and Watt). In addition, translating and applying the laws of nature to exciting and surprising experiments makes it possible to improve students’ understanding about scientific concepts, but above all to arouse students’ fascination and enthusiasm about natural phenomena.

With reference to the difficult aspects of the subject matter of physics, teacher 2 also refers to the abstract level of formalized knowledge; students in the lower grades of secondary education are often too young to think in such an abstract way. Moreover, it is difficult to concretize, represent and illustrate various scientific concepts (e.g., acceleration) partly because of the absence of appropriate experiments, attributes, and examples. Furthermore, physics assignments are complex often requiring many different skills, such as analytical and creative thinking skills, problem solving and calculating/mathematical skills (e.g., application and substitution of formulas). With regard to complicating characteristics of students, many students are lacking important mathematical (e.g., calculating with the metric system) and practical skills (e.g., striking a match), making it difficult to deal with assignments and experiments. In addition, most students don’t have a concrete image of the content and value of physical knowledge due to the fact that they are hardly confronted with physical applications in their daily lives (e.g., media don’t pay very much attention to physics and broken electrical and household appliances are replaced instead of being repaired). Furthermore, students are not motivated to learn the subject matter because their parents don’t stimulate them to do their homework or there is a lack of perseverance because students are spoiled with luxury and immediate fulfillment of their wishes. With respect to school-related aspects, teacher 2 blames the general school policy for repeatedly reducing the amount of weekly courses in the schedule. As a result, time is the deciding factor in considerations about the content of the lessons, the clarifying of scientific concepts and the choice of instructional methods. Furthermore, curricular goals and assessments are revised, leading to a shift in focus from knowledge to general skills and a reduced quality of physics instruction. Moreover, this negative tendency is strengthened both by the lack of qualified physics teachers and by different priorities of the school management.

Teacher 3

According to the third teacher, physics is engaging because of the fact that natural phenomena can be clarified by logical formulas, laws and models. By analyzing physical processes and making abstractions from concrete occurrences, it is possible to build a structured and coherent body of knowledge. However, teacher 3 emphasizes that these logical clarifications of nature should never end up in taking things for granted by loosing the initial fascination about natural phenomena.

Students often perceive the subject matter of physics as ‘difficult’ due to the fact that physical problems and assignments require problem solving skills. Most students start solving a problem by writing down various formulas and calculating many things without exactly knowing what they are looking for. Therefore, students need to learn both how to analyze and define a problem and how to determine a logic and stepwise strategy that leads to the solution. Another complicating factor is related to the fact that students differ in their motivation to learn the subject matter: some students have chosen the subject because they are intrinsically motivated to discover and understand scientific concepts whereas others are more extrinsically motivated, for instance: studying a ‘difficult’
subject might grade up a student’s social status among peer students or the content of physics might be useful for a
student’s future career. Furthermore, teaching physics is sometimes difficult because students don’t easily accept a
teacher’s feedback and/or comments about their work and achievements. For instance, students expect teachers to
explain carefully the process of grading and the various decisive criteria of assessment. With reference to school-
related aspects, teacher 3 points at the organization of whole-class teaching through which specific needs of
individual students might be overlooked. In addition, some teachers don’t have a classroom for themselves and are
repeatedly confronted with a lack of appropriate educational means, such as multimedia and ICT. Finally, many
teachers are charged with various tasks within the school and are consequently lacking time to keep themselves
informed of developments in the field of Modern Physics.

Teacher 4

When it comes to engaging aspects of physics, teacher 4 primarily speaks about the breadth of the subject
matter. Physics encompasses a logical and structured way of thinking about nature by modeling concrete
phenomena in formulas and abstract laws. In addition, the subject matter includes a philosophical component:
scientific models and laws are relative and restricted representations of reality. Furthermore, the field of Modern
Physics is still in a state of flux (e.g., new inventions and advanced understanding of scientific concepts). Physics
education is exciting when natural phenomena are taken as a point of departure: both teacher and students are
triggered by fascinating elements of nature leading to various learning activities and the discovery of scientific
concepts. Obviously, this joint process requires many different skills, for example creative thinking skills, problem
solving skills and practical skills. Finally, besides the fact that teachers have many opportunities to develop varied
lessons, it’s also possible to integrate chemistry and technology.

According to teacher 4, difficult aspects of the subject matter are mainly related to the process of bridging
concrete phenomena and formalized, abstract knowledge; the process of creating meaningful relationships between
concrete empirical data and abstract formulas, models and theories requires both imagination and the ability to
analyze, apply and concretize abstractions to occurrences in daily life and/or to experimental results. In addition,
students struggle with the earlier mentioned philosophical component of physical knowledge, particularly because
the relativity of measures and abstractions consequently leads to a fundamental uncertainty of theories and findings.
Moreover, this feeling is strengthened when students are confronted with surprising experimental results that
contradict their theoretical predictions and expectations. The process of problem solving and learning physics by
investigating natural phenomena often leads to unstructured situations resulting in a strong need for clarification
among students. In addition, applying the subject matter requires a range of different analytical, mathematical,
and problem solving skills (e.g., analyzing, reasoning, calculating, and determining solution strategies). With regard to
students’ characteristics, teacher 4 also points at students’ lack of mathematical, technical and practical skills.
Moreover, students are not always motivated due to a lack of self-confidence, interest, technical experience, or
existing negative prejudices. In addition, some students spoil the relationship with their teacher by not taking
responsibility for their work (e.g., not making a planning or starting too late with assignments) or by not accepting a
teacher’s authority and feedback (e.g., commenting or being rude). Finally, concerning school-related complicating
factors, some parts of the curriculum hardly connect with students’ experiences. In addition, the curricular goals and
content of physics have been revised for several years, resulting in a process of trying out and optimizing new
content and instructional methods. As a consequence, lessons are not always well structured. Finally, teachers are
often lacking time to guide, support, and coach new colleagues and to keep informed about new developments in
the field of Modern Physics.
Cognitive, Affective, and Regulative Learning Activities to make Physics Engaging and Comprehensible for Students

Besides engaging and difficult aspects of physics, we asked the four teachers about the learning activities they arranged to make physics engaging and comprehensible for their students. Analyses of the data show that all teachers arrange all three types of learning activities, namely cognitive as well as affective and regulative learning activities. However, most of the learning activities are focused on the learning of scientific concepts. With reference to activities focusing on learning skills, all teachers stress the training of mathematical, analytical and problem solving skills by using various cognitive learning activities. Three teachers use regulative learning activities and two teachers arrange affective learning activities. Furthermore, only two out of four teachers emphasize values, mostly by using affective learning activities to arouse students’ fascination about natural phenomena (e.g., conducting surprising and exciting experiments) and showing the value of physical knowledge and skills for students’ future lives (e.g., showing applications of physics in Dutch society). Table 3 (included after the References section) shows an overview of learning activities arranged by teachers to make physics engaging and comprehensible.

Table 3. Overview of Physics Teachers’ Activities to Make Physics Engaging and Comprehensible.

<table>
<thead>
<tr>
<th>CONCEPTS</th>
<th>SKILLS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
</tr>
<tr>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>COGNITIVE Learning Activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relating / Structuring</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Analyzing</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Concretizing / Applying</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Memorizing / Rehearsing</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Critical Processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selecting</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>AFFECTIVE Learning Activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivating/ Expecting</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Concentrating/ Exerting effort</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Attributing/ Judging oneself</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Appraising</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dealing with emotions</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>REGULATIVE Learning Activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orienting/ Planning</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Monitoring/ Testing/ Adjusting</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Evaluating/ Reflecting</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

With regard to activities focusing on the learning of scientific concepts, most teachers pay attention to the following cognitive learning activities: ‘relating/structuring’, ‘concretizing/applying’ and ‘critical processing’. ‘Relating/structuring’ activities mainly consist of using multiple perspectives and/or a fixed structure to explain the subject matter. ‘Concretizing/applying’ learning activities often comprise visualizing scientific concepts by drawing pictures or using multimedia to show applications/contexts and ‘critical processing’ is often stimulated by discussing and explaining the subject matter to peer students. Besides cognitive learning activities, teachers often arrange affective learning activities to motivate students, for instance by having a variation in instructional methods and interesting assignments or by enriching the subject matter with actualities (newspaper articles) and surprising facts. In addition, teachers pay attention to students’ emotions by appealing to their perseverance and assuring students that they are competent to learn the subject matter. Finally, regulative activities focusing on learning concepts mainly consist of monitoring/testing/diagnosing students’ understanding and taking students’ differences into account (e.g., using different instructional methods and adjusting the content and speed of explanations to students’ needs).
Conclusions and Implications

In this paper, we investigated the beliefs of four Dutch physics teachers about teaching and learning physics by focusing on the question: How to make physics engaging and comprehensible for secondary students in the Netherlands? We paid attention to teachers’ personal characteristics, their beliefs about engaging and difficult aspects of teaching and learning physics, and the various learning activities they arrange to make their subject engaging and comprehensible.

Results show that all four teachers consider the logical structure of the subject matter of physics as an engaging aspect. They like the possibility to clarify natural phenomena with abstractions, formulas and models and refer to the practical value of scientific skills and knowledge in daily life (e.g., problem solving, analyzing, defining, experimenting, and applying theories). These teachers mainly experience the subject matter of physics as a creative cognitive puzzle with fascinating pieces of natural phenomena and many opportunities to test possible theories and solutions with practical experiments. It seems that teachers’ own fascination with particular aspects of the subject matter influence the focus of their learning activities to make physics engaging and comprehensible. For instance, most learning activities are focusing on the learning of scientific concepts or on acquiring analytical and problem solving skills. Moreover, most affective activities aim to motivate students to see the value of scientific concepts and to understand the logical structure of the subject matter. In line with Talisayon (2008), teachers seem to be mainly focused on the learning of concepts; skills and values seem to function as a means to achieve that goal. However, more research is needed to investigate the relationships between teachers’ preferences for particular aspects of the subject matter and the activities they arrange to make their subject engaging and comprehensible.

With reference to difficult aspects of physics, all teachers share the opinion that the abstract and formalized knowledge of physics (i.e., the abstract scientific concepts) is difficult to learn because students need to have imagination and analytical skills (e.g., modeling, structuring, relating, reasoning in a coherent way) in order to understand abstractions and to apply scientific concepts in concrete contexts. Moreover, students are often lacking important mathematical and problem solving skills and they don’t see the value and relevance of the subject matter. These complicating factors seem to be related to Ogborn’s (2008) distinction between scientific knowledge and commonsense reasoning; many students seem to judge physics concepts by using mainly pragmatic, commonsense-related criteria, for instance by asking to what extent physical knowledge is useful in coping with problems in daily life. Furthermore, it seems that students particularly have problems with imagining scientific concepts (e.g., creating concrete images or pictures of abstractions). Although teachers do arrange learning activities to concretize the subject matter, they admit that it is often difficult to bridge the gap between students’ concrete experiences and the abstract world of scientific concepts. This might be related to the fact that there is a gap between teachers’ own images of scientific concepts and students’ experiences. Therefore, further research is needed to investigate the content of teachers’ own images of scientific concepts and to what extent these images are related to concrete applications or daily life contexts.

Concerning the focus of teachers’ learning activities, only two out of four teachers explicitly pointed at the value of evoking fascination and curiosity about natural phenomena. Both teachers (2 and 4) are very experienced (i.e., over twenty years) and do have an age above fifty years; moreover, a remarkable detail is that both of them studied physics and chemistry. Although all teachers focus on concepts and skills, teacher 1 mainly focuses on the learning of scientific concepts; in addition, he seems to have a preference for intellectual learning activities for he uses nearly all different types of cognitive activities (five out of six). Furthermore, there seems to be a difference between teachers in the amount of different activities they use in order to achieve their goal. For instance, some teachers use multiple activities to concretize and apply the subject matter (e.g., using multimedia, giving examples, searching appropriate attributes or taking natural phenomena as a starting point) whereas others mainly use one activity (e.g. clarifying and training a fixed structure). Further research is needed to investigate the relationships between teachers’ personal characteristics, the amount and nature of the activities they arrange to make the subject engaging and comprehensible, and the focus of these activities. Moreover, we didn’t ask teachers about the details of
these learning activities (for instance, the frequency of activities, the amount of time involved, interaction between teacher and students, aspects of communication, etc.). Therefore, further research is needed to investigate the manifestation of teachers’ beliefs in teaching practices by studying the characteristics of the learning activities.

Concluding remarks

In this paper, we explored teachers’ beliefs about engaging and difficult aspects of teaching and learning physics and the learning activities they arrange to make the subject engaging and comprehensible. We will use the results of this small-scale interview study as input while preparing a large scale survey study on teachers’ beliefs about teaching and learning physics. Moreover, we will investigate teacher behavior in practice, for instance by making observations of learning activities, in order to get more insight in the complicated relationship between teachers’ beliefs about teaching and learning physics and the manifestation of these beliefs in teaching practice.

References


DO BELIEFS CHANGE? INVESTIGATING PROSPECTIVE TEACHERS’ SCIENCE TEACHING ORIENTATIONS DURING AN ACCELERATED POST-BACCALAUREATE PROGRAM

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Abstract
Science teaching orientations have been theorized as a critical component within the Pedagogical Content Knowledge (PCK) model of science teacher knowledge. However, few empirical studies investigate the nature and sources of science teaching orientations. The purpose of this study was to investigate how science teacher orientations develop in an Accelerated Post-Baccalaureate master’s program leading to science teacher certification. Data sources included a lesson planning task at the beginning of the program, interviews after the first summer of coursework, an interview-observation cycle during the prospective teacher’s first and second semester teaching, and interviews with the mentor teachers. The prospective teachers’ science teaching orientations were complex, consisting of multiple dimensions. Although each prospective teacher added goals and/or views of the teacher’s role, their science teaching orientations were highly resistant to change. The mentor teacher had the greatest impact on prospective teachers’ science teaching orientations, and in particular, on the elaboration of goals and views of the teacher’s role.

Introduction
Inquiry-based science (National Research Council [NRC], 1996) is at the core of reform in science education in the U.S. and in other parts of the world. Proponents of inquiry-based science support instruction that emphasizes the role of questions, evidence, and explanation in science (Bybee, 1997). Reform-based pedagogy in science requires that students actively participate by responding to scientific questions, giving priority to evidence, and formulating and justifying explanations (NRC, 2000). Preparing prospective science teachers to enact this vision of science education reform is one of the roles of teacher educators. While this vision of science pedagogy dominates the literature on K-12 education and is the focus of most science teacher preparation programs, researchers have found that classroom practices of teachers across the U.S., and in other countries, are far from achieving this vision. Why is there this disconnect between what reformers, researchers, and teacher educators value and the practices we typically observe in schools? What is the weak link between science teacher preparation and resulting teacher practices? The past 30 years in teacher education research mark a shift from identifying aspects of effective teacher training to understanding the factors that influence the development of teacher knowledge (Cochran-Smith & Fries, 2006). The purpose of this study is to understand the development of prospective science teachers’ knowledge and beliefs about science teaching during a post-baccalaureate teacher certification program in order to explain their practices.
Rationale

Shulman (1996) emphasized that effective teachers blend both content and pedagogical knowledge, and transform these knowledge bases into knowledge specific to teaching, referred to as Pedagogical Content Knowledge (PCK). Magnusson et al. (1999) developed a PCK model for science teaching consisting of five components: (1) orientations toward science teaching, (2) knowledge of curriculum, (3) knowledge of assessment, (4) knowledge of students’ understanding of science, and (5) knowledge of instructional strategies. In examining the “orientations to teaching science component” of the PCK model, an issue arises with the definition of this component. Magnusson, Krajcik, and Borko (1999) retain Grossman’s original definition for conceptions, i.e., “a teacher’s knowledge and beliefs about the purposes for teaching science at a particular grade level” (p. 97) while also including Anderson and Smith’s (1987) broader definition of orientations as, “a general way of viewing or conceptualizing science teaching” (p. 97). So, in changing terminology and drawing on both the work of Grossman (1990) and Anderson and Smith (1987), the definition of orientations to science teaching becomes ambiguous. To bring clarity to this definition, we have drawn on the mathematics education literature (Ernst, 1989; Handal, 2003). Building on this literature, we have expanded Magnusson et al.’s definition of science teaching orientations to include the following dimensions: beliefs about teachers’ goals and purposes for teaching science, views of teaching and learning, and views of teacher/student roles in the science classroom. Researchers have used the term “dimensions” when referring to teacher/student roles and goals and purposes for teaching science (Koballa et al, 2005; Samuelowicz & Bain (1992). By elaborating Magnusson et al.’s definition of orientations, we take a more fine-grained view of the development of prospective teachers’ beliefs within a teacher education program.

Methods

The four participants (Mary, Amy, Lilly, and Jason) were enrolled in an Accelerated Post-Baccalaureate (APB) program. The APB program includes three Secondary Science Methods courses that highlight reform-oriented science teaching orientations (e.g., inquiry, conceptual change, problem-based learning). To document incoming PCK, we used the Lesson Preparation Method based on Valk and Broekman (1999). Participants designed two 50-minute lessons for 8th graders that addressed the following topic, “There is heritable variation within every species of organism.” Following the lesson planning task, we conducted a semi-structured interview (Patton, 2002; Seidman, 1998) with each participant targeted at understanding their orientations and topic-specific PCK for learners, instruction, curriculum and assessment. At the end of the first summer of the ABP, we conducted a second semi-structured interview to allow the participants to review, reflect on, and change their initial lesson plan. During the school year, we conducted an observations cycle during each of the two semesters. The observation cycle consisted of the following: a pre-observation interview, two consecutive field observations of the participant teaching a class, and two stimulated-recall interviews. We also conducted two semi-structured interviews with the mentor teachers, one in the fall and one in the spring. All data collection instruments are available at the project’s website (http://resmar2t.missouri.edu.html).

To analyze the resulting data sets, we used coding categories based on our theoretical framework. The coding scheme consisted of six major categories. (See Brown (2008) for a description of the coding categories.) Based on the coded data, the first author created individual summary cases for each participant (within-case analysis). Any discrepancies were discussed and resolved within the research team. Triangulation was achieved through multiple data sources, lesson plans, interview transcripts, and field observations (Yin, 1994), as well as through multiple researchers (Denzin & Lincoln, 2005). In the second phase of the data analysis, we analyzed the four participants’ cases for patterns and themes that occurred across all four cases (cross-case analysis). The first author generated tentative assertions that were tested during team research meetings, with all members of the research team checking the data to look for confirming and conflicting evidence
Interpretations

We present our interpretations in three sections. In the first section, we use one individual case to show a prospective teacher’s science teaching orientation (Amy), including images of science teaching and learning, goals, teacher roles, and student roles. Additionally, we provide a profile of her mentor teacher’s orientations to science teaching. The individual and mentor teacher profiles provide a context for understanding the factors contributing to the development of prospective teachers’ science teaching orientations. In the second section, we present summary tables of the other three prospective secondary science teachers (Mary, Lilly, and Jason) and their mentor teachers’ orientations to science teaching. (See Brown (2008) for the full profiles for the other secondary prospective secondary teachers (Mary, Lilly, and Jason) and their mentors.) In the third section, we present our cross-case analysis addressing the research questions related to the nature and development of prospective teachers’ science teaching orientations.

Amy’s Case

Experiences Prior to Program

Amy, age 26, graduated with an undergraduate degree in biology and planned to pursue a medical degree. After completing an internship in a hospital, she decided against attending medical school because “the lifestyle of a doctor wasn’t the lifestyle [she] wanted to live.” In Amy’s application materials she described her reasons for changing career paths: “Being a teacher would allow me to give back to society in a positive and rewarding way, while still leaving time for my family and other things in life that I find important.” Amy had numerous informal experiences working with youth as a snowboard instructor, soccer coach, and camp counselor. She wrote at length in her application materials about how she worked closely with adolescents and developed different programs in these contexts to pique students’ interests. Amy also worked in a formal K-12 setting as a substitute teacher. However, she believed her job as a substitute teacher provided her with limited opportunities to plan and teach science content. When Amy described her job as a substitute she said the regular classroom teachers “would give us all the information that they wanted to give.” Additionally, most of her substitute teaching experiences were in elementary classrooms where she “did a lot of babysitting.”

Entry

Based on Amy’s experience as a mentor and a K-16 student, she thought the teacher’s role was to be a leader. Amy emphasized the importance of connecting new content to students’ experiences through teacher-led discussions. She planned to discuss family trees because “it might make it easier [to see the] association of the different traits with the different family members” (Entry Task Interview). Additionally, Amy would highlight important content by leading students during discussions. She mentioned, “While they’re discussing I’ll make notes on the overhead” (Entry Task Interview). Amy focused on the teacher’s role and believed students are responsible for following the teacher’s lead. Amy’s central goals for teaching science were for students to apply science to their lives and to prepare students for future science courses. She explained, “I want my students to not only learn the subject material, but also take away valuable life learning lessons. I want them to learn to think analytically and critically not only in the classroom, but also in their everyday lives” (Video Task). Amy also talked about the importance of preparing students for future courses. She wrote, “I would be satisfied if I was able to cover all of the material on the lesson plan for the day and had time for discussion at the end” (Video Reflection). Amy believed she needed to cover the content so students were prepared for high school science courses.
End of Summer

After 11 weeks of APB coursework, Amy continued to view science teaching as telling and learning as listening. Amy reported it was her responsibility to lead the discussion by presenting terms and concepts, and then provide students with some freedom to work with new ideas. By discussing the concepts with their peers, students would feel a sense of ownership for learning. Amy described her role as a leader:

I would kind of start off initially leading class discussion and then let the kids go on and I’d just walk around and listen and ask questions and kind of pipe in every once in a while. So, they’re feeling like they have control of what they’re talking about. (End of Summer Interview)

Although Amy learned about student-centered activities from the Science Methods course, her beliefs about teaching remained teacher-centered. During the end of the summer interview, Amy focused on her responsibilities during the lesson and still believed students have a passive role and are responsible for following the teacher’s lead.

Amy’s central goal for teaching science persisted; she wanted to present science content so students could apply their science knowledge to their lives. In her lessons on heredity, she wanted students to think deeply about variation found in nature. She stated:

It’s not just within humans, but that there’s a reason why everything’s different. There’s a reason why in Missouri we don’t have palm trees and in Florida they do. And just that … that there is genetic variation or whatever within such a large species, that’s the reason why. (End of Summer Interview)

Amy still held a central goal of preparing students for future science classes. She said, “Just to give them kind of a solid framework to work with whenever they are taking a genetics course later in high school or in college. They can look back and go, oh, I remember” (End of Summer Interview). Amy believed students learn science in 8th grade to prepare for high school science courses.

Internship Context

For the 2006-2007 school year, Amy was placed in an internship with an experienced mentor, Irene, at Rover High School. Irene was a veteran teacher (25+ years) with National Board certification. As the chair of the science department, Irene believed teachers who taught the same courses should meet frequently to design a common curriculum that included: lessons, assessments, and unit objectives supported by state and national standards. Prospective teachers were encouraged to participate in weekly science faculty meetings and contribute teaching ideas for meeting the unit objectives. Amy took part in the weekly biology group meetings and described them by saying “we try to do it exactly the same as the other honors biology. So the beginning of the week before each new unit, we all get together and kind of go over what we’re doing” (Pre-observation Interview).

Irene (Amy’s mentor) believed prospective teachers needed to observe and mimic experienced mentors. While the prospective teachers mimicked her teaching style, Irene cotaught with the prospective teacher so she could add her science knowledge and experiences during the lessons. Irene believed coteaching helped prospective teachers learn about instructional pace and timing, and ensured the prospective teachers kept the same pace with other biology classes. As prospective teachers gained experience, Irene allowed them to use the unit objectives and common assessments to design their own instructional activities. After prospective teachers gained experience, Irene still used a coteaching approach, but did not have prospective teachers observe and mimic her style. Amy described her internship experiences, “I have not done a lot of the actual planning … I probably teach at least half of every hour. Some days I teach the whole hour, but Irene and I generally coteach things together” (Pre-observation Interview). When Amy created her own notes and quizzes she talked about using her mentor’s lectures as a guide: “I usually generally take her notes … and make up my own notes based on that. It’s not starting from scratch by any means” (Pre-observation Interview).
Mentor Teacher's Science Teaching Orientation

Irene’s view of teaching and learning focused on setting and meeting objectives. She said, “we have pretty high expectations in our Biology classes. For example that yes, this is the level they will learn, this is the amount they will learn, these are the kinds of experiences they will have.” For Irene, teaching is more than telling. Teachers need to provide lots of opportunities for students to practice new information. The teacher’s role is to select the objectives for the lesson and to design activities that will help students meet the objectives. The activities might include lectures, labs, stations, and class discussions. It’s the teacher’s job to informally assess student learning and to provide opportunities for students to assess their own progress toward meeting the objectives. It is also the teacher’s job to provide standards to illustrate what it means to meet a specific objective. The students’ role is to do what the teacher asks. She thought that when students are actively engaged and asking lots of questions they learn science better. Additionally, she likes days when labs don’t work. She said, “I love to do a lab and it isn’t working and I don’t know why because then we all have to figure it out.”

Irene was able to easily express her overall goals and purposes for teaching high school biology. She explained, “My job is help you be smarter.” When probed to define what this meant, she referred to Bloom’s Taxonomy. She wants students to be able to analyze, evaluate, and synthesis new information. She wants students to have the skills so that “when they have a situation, they can say, oh, what should I do here?” Irene stated that she wanted students to “have some sense of the world around you.” She wanted her students to become educated adults so that they could be good citizens. She also wanted to prepare them to take future biology courses.

Fall and Spring Semester

Amy retained the view that science teaching is telling and learning is listening. She explained, “The role of the teacher was to provide guidance for the daily class activities and to make sure the students are staying on task. You are giving them the materials that they need in order to understand the objective” (Fall Interview). Amy was working on becoming more assertive and directive with students. Amy commented, “One of the main things we’ve been working on is, just being more drill sergeant-like, telling students pick up your piece of paper, write these three things down, do this” (Fall Interview). Accordingly, the students’ role was to follow the teacher’s lead. She explained:

The student’s role is to … do what we’re asking them to do and be a student … The role of the student is to come to school and be prepared for whatever, and the teacher needs to be prepared to do. The student needs to be prepared to learn and turn in their homework assignments, those kinds of things and just to learn. (Spring Interview)

According to these views, Amy believed the central goal of science teaching was to present science terms and concepts to students. She explained:

Most of this biology stuff is kind of new to them so I feel like we have to start from the beginning, like this is what DNA is because they don’t have any previous knowledge on that. But once we start giving them information, they pick it up really quickly and they’re able to apply new knowledge to the old knowledge. (Fall Interview)

Amy focused on the importance of presenting content to students because she thought the biology content was new to students.

During the fall semester, because of the unit she was teaching, Amy’s goals changed and she focused on presenting content so students were ready to make scientifically-based decisions. She thought science class was a place for students to receive accurate information about different types of cloning such as therapeutic and reproductive cloning. According to Amy,

I want them to realize that that’s not the only kind of cloning [referring to reproductive cloning] that, there are variants to that. Just to give them a broader understanding of something that they
obviously have heard about, with the elections that were just a few months ago, so they've known something about it and have heard something about it. (Fall Interview)

Amy talked about students needing to be informed because the media’s portrayal of cloning is not always scientifically accurate.

**Development of Amy’s Science Teaching Orientation**

Amy entered the APB program believing science teaching is telling and learning is listening based on her observations of science teachers who primarily used delivery modes of instruction. This view was strongly reinforced in her internship where she observed, mimicked, and taught using primarily teacher-centered practices. Amy believed that Irene’s mentoring was vital for her professional growth as a teacher and without the mentoring she believed, “I wouldn’t be able to do it all I don’t think. I wouldn’t be comfortable as a first year teacher (Spring Interview). Amy reflected on how the APB coursework influenced her beliefs about science teaching. Amy thought the Secondary Science Methods course instructors focused only on inquiry-based teaching strategies. She said, “I feel like in school [referring to the Secondary Science Methods courses] they don’t always give you that other way. It’s always inquiry based” (Spring Interview). Even though she learned new instructional strategies, like the 5E instructional model, and how this sequence relates to student learning, she reflected exclusively on the internship when speaking about how she learned to teach. She explained in detail:

I think that the courses at the university you learn all of these things, you learn about classroom management, you learn about the different teaching philosophies in Educational Psychology and all of that kind of stuff. You learn about this 5E instructional model, and so I have it all there but I don’t really use it … So, I think the most beneficial thing for me was my student teaching and working with my mentor teacher where I can say, when she gives me a whole unit to do, I can try to use all of that stuff that I’ve learned and implement it with her advisory and her saying ‘oh, no we’ve tried this before. This is going to work.’ (Spring Interview)

Although Amy added additional goals during the fall and spring semesters, there is little evidence that she held other orientations to science teaching during nine months of the APB program. Over time, Amy’s science teaching orientation was highly resistant to change and remained stable over time.

Summary of Mary’s, Lilly’s and Jason’s Orientations to Science Teaching

In this section, we present the other three participants’ science teaching orientations. Due to space constraints, their orientations are presented in Tables 1, 2 & 3.

**Table 1. Development of Mary’s Orientation to Science Teaching**

<table>
<thead>
<tr>
<th>Dimensions: Views of teaching and learning</th>
<th>Mary’s Orientation</th>
<th>Mentor Teacher’s Orientation</th>
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<tbody>
<tr>
<td>Views of the teacher’s role</td>
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<td>Views of the students’ role</td>
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<td>Central goals</td>
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<thead>
<tr>
<th>Entry</th>
<th>End of Summer</th>
<th>Fall/Spring</th>
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<tbody>
<tr>
<td>• Teaching is telling, learning is listening</td>
<td>• Teaching is telling, learning is listening</td>
<td>• Teaching is telling, learning is listening</td>
</tr>
<tr>
<td>• Leader</td>
<td>• Leader</td>
<td>• Leader</td>
</tr>
<tr>
<td>• Follower</td>
<td>• Follower</td>
<td>• Follower</td>
</tr>
<tr>
<td>• For students to apply science to life</td>
<td>• For students to apply science to life</td>
<td>Present content</td>
</tr>
<tr>
<td>• Build on students’ prior knowledge</td>
<td>• Build on students’ prior knowledge</td>
<td>NM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mentor Teacher’s Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Teaching is telling, learning is listening</td>
</tr>
<tr>
<td>• Present Content (Leader)</td>
</tr>
<tr>
<td>• Knowing terms and concepts that the teacher presents (Follower)</td>
</tr>
<tr>
<td>• Covering content in school’s curriculum</td>
</tr>
<tr>
<td>• Preparing students for college</td>
</tr>
</tbody>
</table>

Note. NM= Not mentioned
Table 2. Development of Lilly’s Orientation to Science Teaching

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Entry</th>
<th>End of Summer</th>
<th>Fall/Spring</th>
<th>Mentor Teacher’s Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Views of teaching and learning</td>
<td>Teaching is telling, learning is listening</td>
<td>Teaching is telling, learning is listening</td>
<td>Teaching is telling, learning is listening</td>
<td>Teaching is telling, learning is practicing</td>
</tr>
<tr>
<td>Views of the teacher’s role</td>
<td>Leader</td>
<td>Leader/Guide</td>
<td>Leaders/Guide</td>
<td>Teach and re-teach (Leader)</td>
</tr>
<tr>
<td>Views of the students’ role</td>
<td>Follower</td>
<td>Follower</td>
<td>Follower</td>
<td>Practice new terms and concepts (Follower)</td>
</tr>
<tr>
<td>Central goals</td>
<td>Preparing and motivating students for future courses</td>
<td>Preparing and motivating students for future courses</td>
<td>NM</td>
<td>Cover state standards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Letting students choose the content they want to study</td>
<td>For students to apply science to life</td>
<td>Prepare students for state mandated test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For students to have fun</td>
</tr>
</tbody>
</table>

Table 3. Development of Jason’s Orientation to Science Teaching

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Entry</th>
<th>End of Summer</th>
<th>Fall/Spring</th>
<th>Mentor Teacher’s Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Views of teaching and learning</td>
<td>Process of discovering knowledge so students can apply science to life</td>
<td>Process of discovering knowledge so students can apply science to life</td>
<td>Process of discovering knowledge so students can apply science to life</td>
<td>Teaching is telling, and learning is listening</td>
</tr>
<tr>
<td></td>
<td>Teaching science is providing content through teacher-led discussions and learning is participating in discussions</td>
<td>Teaching science is providing content through teacher-led discussions and learning is participating in discussions</td>
<td>Teaching science is providing content through teacher-led discussions and learning is participating in discussions</td>
<td></td>
</tr>
<tr>
<td>Views of the teacher’s role</td>
<td>Guide</td>
<td>Guide</td>
<td>Guide</td>
<td>Deleiver content through lectures and readings (Leader)</td>
</tr>
<tr>
<td>Views of the students’ role</td>
<td>Discoverer</td>
<td>Discoverer</td>
<td>Discoverer</td>
<td>Follow the teacher’s lead (Follower)</td>
</tr>
<tr>
<td>Central goals</td>
<td>For students to apply science to life</td>
<td>For students to apply science to life</td>
<td>For students to apply science to life</td>
<td>Present content from district curriculum and state standards</td>
</tr>
<tr>
<td></td>
<td>For students to discover science knowledge on their own</td>
<td>For students to discover science knowledge on their own</td>
<td>For students to discover science knowledge on their own</td>
<td>Provide students with background knowledge</td>
</tr>
<tr>
<td></td>
<td>Prepare students for future classes</td>
<td>NM</td>
<td>NM</td>
<td></td>
</tr>
</tbody>
</table>
Cross-Case Assertions: Prospective Secondary Teachers’ Science Teaching Orientations

Assertion 1: Prospective teachers formed their science teaching and learning orientations based on their K-16 learning experiences and other background experiences. Incoming science teaching orientations were robust and highly resistant to change.

All four teachers held teaching orientations shaped by their background experiences as K-16 students and youth mentors. Mary, Amy, and Lilly entered the APB program with science teaching orientations primarily influenced by their experiences as students. These three prospective teachers were highly committed to the view that science teaching is transferring knowledge to students (see Tables 1-3). Jason held an orientation to science teaching that was largely based on his experiences mentoring Christian youth groups where he was successful in using discussions to help students discover life lessons. However, Jason experienced delivery modes of instruction as a K-16 student. Jason held competing conceptions based on these background experiences. Ideally, he hoped he could guide students in discovering science on their own through discussions. However, there are great differences between using discussions to discover life lessons, and using discussions to discover science concepts. Scientists do not discover general principles from particular terms, concepts, or instances. Rather, scientists invent theories that are checked against observations, experiences, and empirical data. From watching his K-16 science teachers, Jason believed he needed to use teacher-led discussions to provide students with new terms and concepts. Because of his experiences mentoring youth and his contrasting experiences as a student, Jason held competing conceptions of teaching and learning (see Table 3).

Although the participants gained additional goals and views of the teacher’s role, the central components of their science teaching orientations were robust and did not change significantly throughout the APB program (see Tables 1-3). Mary, Amy, and Lilly consistently believed that teaching is telling and learning is listening. These three individuals believed the teacher’s role is to lead students who have a passive role (i.e., “followers”) in learning science (see Tables 1-3). Similarly, Jason’s orientation did not change significantly. During the APB program, Jason had two views of teaching and learning: (a) learning is a process of discovering knowledge so students can apply science to life, and (b) teaching is providing content through teacher-led discussions and learning is participating in discussions. According to these views he believed that teachers are responsible for guiding students while the students’ role is be open-minded and inquisitive so they discover some science content on their own (see Table 3).

Assertion 2: The mentor teachers re-enforced dimensions of the prospective teachers’ incoming science teaching orientations and had the greatest influence on the elaboration of prospective teachers’ science teaching orientations. Further elaborations (i.e., additional goals and views of the teacher/student roles) were congruent with the prospective teachers’ incoming science teaching orientations.

Mary, Amy, and Lilly were assigned to work with mentor teachers who predominantly used traditional, transmission types of instruction, and the mentors strongly reinforced the prospective teachers’ incoming science teaching orientations (see Tables 1-3). These three prospective teachers gained knowledge that was congruent with dimensions of their science teaching orientation. Mary and Lilly learned from their mentor teachers that learners need multiple exposures to new content to memorize vocabulary. Amy learned that she needed to break-up lectures with peer teaching, which meant to her that students practice the ideas covered in lectures to help them commit vocabulary to memory. These views of the requirements for learning meshed with their views of teachers as leaders and/or guides who are responsible for transmitting knowledge to students.

Jason was also assigned to work with a mentor who primarily used teacher-centered types of instruction. During his internship, Jason developed a goal of having students learn science vocabulary. During teacher-led discussions and lectures he focused on terms and concepts that were addressed in his school’s science curriculum. The addition of this goal aligned with his belief that students need teacher-led discussions (see Table 3). Due to the nature of his mentor teacher’s instructional practices, Jason did not replace his ideas about discovery learning and
discussions with more accurate conceptions of how science knowledge is invented rather than discovered. As a result, his conflict of using teacher-centered discussions persisted throughout the ABP program.

**Assertion 3:** Prospective teachers’ science teaching orientations acted as filters for making sense of experiences during the APB program.

During the nine months of the APB internship, the prospective teachers interpreted experiences based on their science teaching orientation. For example, as a result of the Secondary Science Methods courses, Mary’s view of teaching and learning expanded to include building on students’ prior science knowledge. For Mary, this translated into beginning her lectures with content familiar to her students. Due to the cloning unit she was teaching, Amy’s goals expanded to include preparing students to make educated decisions. She led discussions with students about the positive and negative aspects of therapeutic and reproductive cloning. After the first summer in the APB program, Lilly thought that teachers should let students have some choices when deciding what content to study. In the fall, Lilly let students manipulate variables in a laboratory investigation, but only after she lectured on diffusion and osmosis, had students complete worksheets practicing new terms and concepts, and conducted a similar cookbook laboratory investigation with the students. Even though these teachers added goals for teaching science to their orientations, their views of teaching and learning remained consistent throughout the APB program. They believed that learning is best facilitated through teacher-centered practices such as lectures and teacher-led discussions. The prospective teachers’ additional goals and views of the teacher/student role were congruent with their views that teaching is telling and learning is listening. Mary, Amy, and Lilly’s science teaching orientations acted as a barrier to developing more sophisticated PCK. Amy, Mary, and Lilly never became dissatisfied with their view of teaching is telling and learning is listening. As a result, these three teachers struggled to embrace reform-oriented views of teaching and learning because these views deviated from their science teaching orientations and their experiences working with their mentors.

Jason’s orientation also acted as a filter for making sense of his experiences in the APB program. He drew on multiple experiences during the APB program to try and resolve tensions in his views of teaching and learning. Jason drew on his youth group mentoring experiences because he was dissatisfied with his K-16 experiences that were mostly traditional and teacher-centered in nature. He was eager to find new ways to think about science teaching that mirrored his work with Christian youth groups. As a result, he embraced some of the strategies presented in the Science Methods courses because they provided intelligible ways for him to make teaching and learning more student-centered. For example, he tried to sequence science instruction in a 5E during the spring semester. Although he had students make scientific claims based on evidence during his 5E unit on cells, he thought he needed to begin the lesson with a lecture over cellular structure and function. Thus, his view that teaching and learning is primarily facilitated through teacher-led discussions influenced his knowledge of sequencing science instruction through the 5Es.

Jason entered the APB program with more student-centered views of teaching than the other three participants. Jason’s conflict was a result of the interaction taking place between his different views of teaching and learning. At the end of nine months in the APB program, Jason was in the process of restructuring his knowledge of teaching and learning. Implementing the 5E instructional model and replacing views of discovery learning may require a more radical re-structuring of Jason’s science teaching orientation. Ultimately, Jason was unable to completely abandon his beliefs about using traditional instructional strategies focused on explaining content to students.
Implications and Conclusions

The findings of this study indicate that teacher educators must identify and attend to prospective teachers’ science teaching orientations. As a result of background experiences, the prospective teachers came to teacher preparation with strongly held science teaching orientations. Science teaching orientations are theorized to be important indicators of classroom practice (Grossman, 1990) and the development of PCK (Magnusson et al., 1999). Thus, teacher educators must identify science teaching orientations at the onset of a teacher preparation program. Teacher educators are responsible for explicitly addressing views of teaching and learning that are beneficial for their students and those views that are not conducive to effective science teaching and learning. Additionally, prospective teachers must examine their views of teaching and learning in light of reform-oriented science teaching orientations. Russell and Martin (2007) suggest that teacher preparation might be better viewed as a process of conceptual change. Science methods courses and field experiences need to help prospective teachers become dissatisfied with traditional, teacher-centered science teaching orientations while providing intelligible, alternative science teaching orientations. By creating conditions for cognitive conflict and time for thoughtful reflection, teacher educators can support prospective teachers in re-conceptualizing their view of teaching and learning.

All four of the participants relied heavily on their mentor teachers’ guidance when deciding how to teach. In fact, many of the participants viewed the internship as separate from what they learned in the APB science methods courses. At times, the views of the mentor teachers were in direct opposition to the reform-oriented practices proposed in the APB program. Because many APB programs require a significant amount of experience teaching with a mentor, and novice teachers lack PCK, prospective teachers are heavily influenced by their mentor teachers. As teacher educators, greater attempts must be made to ensure that mentor teachers’ practices and science teaching orientations align with the values of the Science Methods courses. For example, local teachers who are graduate students may be ideal mentor teachers because they are learning about reform-minded practices in their coursework. Over time, this may be a strategy to create a cohort of reform-minded mentor teachers. This could be a strategy to create a mentor-teacher social network where mentors can draw on each other and university faculty for support. Mentor teachers could share ideas for best practice, and university faculty could provide mentors with content and theory discussed in science methods courses.

The significance of researching the interaction between science teaching orientations and the development of teacher knowledge is profound. Teacher candidates come to teacher education programs with well established orientations to science teaching that are primarily based on their K-16 experiences. Their incoming science teaching orientations significantly shape how they make sense of what they learn in methods courses and field experiences. While science teaching orientations could be a powerful support for future learning, they can also act as a barrier to the development of knowledge of teaching and learning. If initial science teaching orientations are not elicited and engaged, then prospective science teachers may fail to develop reform-oriented science teaching orientations and practice. Prospective teachers must become dissatisfied with their science teaching orientations that are teacher-centered while simultaneously finding alternative orientations intelligible, plausible, and fruitful in science teaching. This study contributes to our understanding of how science teacher orientations develop during teacher preparation programs. Revealing and confronting science teaching orientations during the course of teacher preparation is critical to the development of teacher knowledge. Teacher preparation programs that take into account the teaching orientations of their participants have a greater probability of impacting teacher practices and student learning.
References


BELIEFS, KNOWLEDGE AND PRACTICES OF TWO EFFECTIVE PRIMARY SCIENCE TEACHERS

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Edith Cowan University

Vaille Dawson
Curtin University

Abstract

Within the literature, there is little research examining how effective primary teachers actually draw on their beliefs and knowledge to develop a coherent and integrated sequence of lessons over the course of a science topic. To address this gap, this doctoral research has focused on what effective primary teachers are doing to promote student understanding of science and what experiences, knowledge and beliefs have influenced their practice. Two primary school teachers, nominated as effective teachers of science, participated in Phase 1 of this study. Data was collected through classroom observations of science lessons and teacher interviews about their beliefs and knowledge regarding science teaching and learning. This paper summarises the preliminary findings drawn from the Phase 1 of the study. Several themes were identified as characterising the beliefs, knowledge and practices of the two teachers. It was found that the beliefs and knowledge of the teachers influenced how they teach science in their classrooms and why they teach science in the ways they do. The themes were reflective of the different contexts that the teachers were working within and were essentially linked to the development of student interest towards and understanding of science.

Introduction

The notion of ‘effective teaching’ is slippery and with understandings of ‘effectiveness’ based on the experiences and opinions of various stakeholders, the task of unravelling what counts as ‘effective teaching’ is a difficult one. The literature on teacher effectiveness has generated numerous lists of behaviours and attributes (e.g. Brophy & Good, 1986; Hattie, 2003). While these lists have assisted in developing a clearer picture, there is still a general lack of consensus regarding a definition. Within education, a commonsense definition may suggest that effective teaching assists students to learn. However, despite some support for this, there is no universal agreement among researchers regarding what effective teaching is (Tuckman, 1995). Perhaps underlying this debate is Ornstein’s (1986) comment that “because we are not able to define precisely what a good teacher is, we can define good teaching any way that we like – so long as it makes sense” (p.176). This implies that we should look towards the features of teaching that work within particular contexts or environments. For example, considering the influence that time, place, teaching discipline, student age, country, culture and student ability have on interpretations of effective teaching.

There are three key Australian research documents that have identified characteristics of effective science teaching in Australian schools. These documents are the National review into the status and quality of science teaching and learning in Australian schools (Goodrum, Hackling & Rennie, 2001), the Professional standards for highly accomplished teachers of science (Australian Science Teachers Association and Monash University, 2002), and the components of effective science teaching as developed by the School Innovation in Science (SIS) Project (Tytler, 2002). The frameworks that these
studies provide are useful tools in better understanding the different aspects of effective science teaching. Analysis of these documents (Hackling & Prain, 2005) identified a strong convergence around six characteristics:

1. Students experience a curriculum that is relevant to their lives and interests;
2. Classroom science is linked with the broader community;
3. Students are actively engaged with inquiry, ideas and evidence;
4. Students are challenged to develop and extend meaningful conceptual understandings;
5. Assessment facilitates learning and focuses on outcomes that contribute to scientific literacy; and
6. Information and communication technologies are exploited to enhance learning of science with opportunities to interpret and construct multimodal representations.

(Hackling & Prain, 2005, p.19)

These characteristics may help to shed light on the nature of effective science teaching, but on their own they cannot bring effective science teaching to life. Effective science teachers may be able to demonstrate particular attributes or traits, but little is understood about precisely what beliefs and knowledge drive their practice. Therefore, it is not clear why effective teachers’ actually do what they do.

Rationale

The tendency for primary teachers to shy away from the teaching of science is well documented (e.g.: Appleton, 2006; Tytler, 2007). In fact, research has suggested that as little as 3% of teaching time, on average, is allocated to the teaching of science within Australian primary schools (Angus, Olney, & Ainley, 2004). Further concerns are raised in light of the national assessments of Year 6 students’ science literacy (MCEETYA, 2005; 2008) conducted in 2003 and 2006, which indicated that more than 40% of students in the sample failed to achieve the proficient standard. Armed with statistics such as these, the need to bring about change is evident. However, to improve outcomes the powerful influence that teachers have on student learning needs to be harnessed (Hattie, 2003). To do this an understanding of what constitutes effective science teaching is required.

To further develop our understanding effective science teaching, this doctoral study has focused on what primary teachers are doing to promote learning in science and what experiences, knowledge and beliefs have led to perceptions of them being effective practitioners. This paper focuses on an aspect of this larger study by examining the beliefs, knowledge and practices of two teachers, Deanne and Lisa (pseudonyms).

Methods

Deanne and Lisa were nominated for involvement in this study through being identified as effective practitioners of science by a professional colleague. With a career in primary education spanning 25 years, Deanne has gathered teaching experience from several schools in remote, rural and urban areas of Western Australia. Deanne has been working at her current school for the past 14 years. Lisa has 14 years teaching experience working in remote and rural primary and secondary schools across Western Australia. With a background in science, Lisa completed a degree and honours project in the area of biology before studying to become a teacher. The research method being used to report on Deanne and Lisa’s beliefs, knowledge and practices on entering this study was a pilot case study methodology (Yin, 2003).
Deanne

At the time of the data collection, Deanne was teaching a Year 6/7 class. Her class of 26 students (10 males and 16 females) comprised 13 Year 6 students and 13 Year 7 students. In Western Australia, Year 7 is the final year of primary school. Information about Deanne’s beliefs, knowledge and practices were collected through classroom observations and an interview.

In Term 4 2007, Deanne and her students were observed for two 100 minute science lessons. The lessons were based on a Primary Connections unit – Marvellous Micro-organisms (Australian Academy of Science, 2005) – which examines the role of micro-organisms through the bread making process. The first lesson was a continuation of an investigation that the class was conducting on moulds and their growth on different types of breads. During this lesson, the students were recording their observations of mould colour, type and growth pattern on each piece of bread. Two days later, the students worked in small groups to conduct an activity looking at the effect of different water temperatures on yeast. Throughout these classroom observations comprehensive field notes were taken.

Two weeks later, Deanne was interviewed to gather information regarding her thoughts and ideas about science teaching and learning. In particular, Deanne was asked about what she thinks about when planning a science lesson, what she hopes her students achieve from a science lesson, what she identifies as a successful science lesson and her thoughts about what characterises effective science teaching.

Lisa

At the time of data collection, Lisa was teaching a Year 3/4 class. Her class of 26 students (18 males and eight females) comprised eight Year 3 students and 18 Year 4 students. Information about Lisa’s beliefs, knowledge and practices were also collected through classroom observations and an interview.

In Term 4 2007, Lisa and her students were observed during two very different science lessons with one lesson running over the course of a day and the other for 60 minutes. The lessons, based on units of Lisa’s own design, examined students’ investigative skills and the life cycle of plants, respectively. The first lesson was part of a whole school ‘extended’ investigation, which mapped student progress and ability in terms of investigative science skills across the year and from year to year. In this lesson, the students examined and manipulating O-wing gliders. Students worked as a class to plan this investigation and worked in small groups for the conducting phase. Each student individually completed a booklet documenting their results and analysis of the findings. Six days later, the students were involved in an activity, which required them to move around the schoolyard to observe and record four different types of flowers. The students’ observations included providing a written description of their flower, the dimensions of the flower and a labelled diagram. Throughout these classroom observations comprehensive field notes were also taken.

Two days later, Lisa was interviewed to gather information regarding her thoughts and ideas about science teaching and learning. As with Deanne, Lisa was asked about what she thinks about when planning a science lesson, what she hopes her students achieve from a science lesson, what she identifies as a successful science lesson and her thoughts about what characterises effective science teaching.

The data collected from these two sources were examined for the beliefs, knowledge and practices characterising Deanne and Lisa’s practice. Several themes emerged from the data and were identified through being mentioned or observed numerous times. These themes were presented to Deanne and Lisa for further clarification. Using an inductive approach to the data analysis allowed for the emergence of Deanne and Lisa’s beliefs and practices rather than imposing existing ideas or thoughts on the data that were gathered (Corbin & Strauss, 2008).
Results

The table below summarises the themes that were identified in relation to the beliefs held, knowledge applied and practices used by Deanne and Lisa. Identification of these themes were based on the data collected through classroom observations and teacher interviews in Phase 1 of this study.

Table 1. Themes characterising Deanne and Lisa’s beliefs, knowledge and practices regarding science teaching and learning.

<table>
<thead>
<tr>
<th>Deanne</th>
<th>Lisa</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Creation of a science-rich/science-friendly environment</td>
<td>• Building students’ science knowledge and skills</td>
</tr>
<tr>
<td>• Use of variety in classroom activities and pedagogy</td>
<td>• Understanding and catering for students’ needs and interests</td>
</tr>
<tr>
<td>• Explicit teaching of science skills and concepts</td>
<td>• Teaching in concrete ways</td>
</tr>
<tr>
<td>• Teaching in concrete ways</td>
<td>• Explicit teaching of investigative process</td>
</tr>
<tr>
<td>• Preparing students for future science learning</td>
<td>• Importance of planning and preparation</td>
</tr>
<tr>
<td>• Development of personal science knowledge</td>
<td></td>
</tr>
</tbody>
</table>

While the two teachers held differing sets of beliefs and knowledge about science teaching and learning, they each enacted aspects of these beliefs and knowledge within their classroom practices.

Conclusions and Implications

Six themes reflected Deanne’s beliefs, knowledge and practices regarding science teaching and learning. An exploration of Deanne’s beliefs, knowledge and practice has identified some of the ways that the emergent themes are in keeping with the literature examining effective science teaching. In relation to the characteristics of effective science teaching derived from the Australian literature (Hackling & Prain, 2005), areas such as using curriculum relevant to students, active engagement of students with science ideas and assisting students to develop meaningful conceptual understandings could be identified within Deanne’s beliefs and practice. Deanne did make passing references to the development of community links through using visiting speakers and the use of information and communication technologies (ICTs) by students searching for information of the Internet. However, they were not prominent within the data collected on Deanne’s classroom practice and her beliefs about science teaching and learning. Deanne made no mention, nor were there any evidence in her observed lessons, of using assessment to assist student learning. The limited evidence obtained in relation to these three characteristics (community links, use of ICTs and assessment for learning) may be related to the very small sample of Deanne’s teaching that was observed and to contextual factors, such as the topic.

Emerging from this case study were Deanne’s additional beliefs about creating an appropriate classroom ‘environment’ for the teaching and learning of science, preparing students for science in high school and the development of the teacher’s personal science knowledge.
Five themes reflected Lisa’s beliefs, knowledge and practices regarding science teaching and learning. An exploration of Lisa’s beliefs, knowledge and practice also identified that some of the emergent themes were in keeping with the literature examining effective science teaching. In relation to the characteristics of effective science teaching, areas such as using curriculum relevant to students, active engagement of students with science ideas through inquiry-based methods and assisting students to develop meaningful conceptual understandings could be identified within Lisa’s beliefs, knowledge and practice. While Lisa did not make specific reference to the use of information and communication technologies (ICTs), the use of different technologies (e.g. interactive whiteboard, digital microscope) as part of her teaching and learning approach in science were prominent in her classroom practice. Similarly, Lisa did not express her ideas about assessment and the ability to contribute to scientific literacy, but again it was evident in her practice. In the observed lessons, Lisa’s students undertook the four phases of an investigation (planning, conducting, processing the data and evaluating) and developed skills in drawing labelled scientific diagrams. While Lisa made no mention, nor were there any evidence in her observed lessons, of connecting the science in her classroom with the broader community, this could be connected to the very small sample of Lisa’s teaching that was observed and to contextual factors, such as the topic.

Emerging from this case study were also Lisa’s additional beliefs and knowledge about the need to explicitly teach students about the investigative process and the importance of teachers’ planning and being prepared for the teaching of science.

It is important to consider that these themes reflect the contexts that Deanne and Lisa were working within, which suggests that the themes are bounded by factors such as parental expectations, the science topic being taught and the year level it is being taught to. These two case studies illustrate how the beliefs, knowledge and practice of a teacher may be influenced by the context. The beliefs and knowledge held by Deanne and Lisa regarding each of the themes are not only enacted throughout her practice, but strongly intertwined with their practices making it difficult to separate the themes into separate entities. Deanne and Lisa’s beliefs and knowledge seemed to have a significant influence on their practice, in terms of how they teach science in their classrooms and why they teach science in the ways they do. Their beliefs and practice have also developed in relation to contexts they work within. This interconnectedness between Deanne and Lisa’s beliefs, knowledge, practices and context suggests that effective science teaching is quite dynamic in its nature and consist of components that interact in different and changing ways.

References


DIFFERENT APPROACHES TO MEASURE TEACHERS’ 
PEDAGOGICAL CONTENT KNOWLEDGE

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Abstract

Teachers’ pedagogical content knowledge (PCK) as a facet of professional knowledge has been shown to be an important factor influencing quality of instruction. PCK embraces the idea that teachers have a special notion of content knowledge and pedagogy which they draw on in teaching contents. In this regard, PCK describes the teacher’s understanding of fostering students’ learning process and understanding of specific subject matters. As there is a lack of instruments to investigate PCK in natural sciences, reliable and valid tests are yet to be constructed. Closing this gap, the following papers present different approaches on measuring teachers’ PCK, for example different test-designs for diverse subjects and school-forms. The measurement of PCK will be presented regarding biology, technology and physics content for primary and secondary school teachers as well as pre-service teachers and students. Additionally advantages and disadvantages of open-ended and multiple choice items and their analysis will be discussed.

Introduction

It is a natural interest of educators to investigate aspects of teachers’ professional knowledge. Already Shulman (1987) presents a classification of components of teachers’ professional knowledge with pedagogical content knowledge (PCK) as a central aspect. PCK is described as a kind of ‘amalgam’ of content knowledge with pedagogical and psychological knowledge as well as with teachers’ personal experiences. Therefore PCK also encompasses an understanding of how certain topics, problems or issues ought to be presented and adapted to the learners’ different interests and abilities (Bromme, 1997; Shulman, 1987). According to recent conceptualizations of teachers’ professional knowledge PCK is one of the most crucial sub-domains (e.g. Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Shulman, 1987; Van Driel, Verloop, & De Vos, 1998).
Shown by several international comparative studies on mathematics instruction PCK became a fruitful field of research to explain differences in students’ achievement. To investigate those varieties regarding students’ outcomes current studies focus not only on classroom criteria but also on teacher characteristics. In this context the LMT-study (Hill, Rowan, & Ball, 2005) and the German COACTIV-study (Krauss et al., 2008) showed that mathematics teachers’ PCK is a good predictor for students’ achievement as well as for quality of instruction in mathematics lessons. Similar results were found by Jones and Moreland (2004) who investigated PCK in the context of primary technology education. As PCK is a part of teachers’ professional knowledge a model of professional knowledge as a whole is needed, validated by means of an appropriate test instrument.

The difficulties in measuring PCK are e.g. to find items which can be judged as right or wrong regarding science educational theories and findings and to decide which context-information teachers need in item-stems for an adequate response (Baxter, 1999; Carlson, 1990; Kromrey & Renfrow, 1991). Referring to Shulman (1987) PCK is defined as knowledge of how to explain contents in a lesson and make them understandable for students. Obviously it is not easy to agree on a ‘gold standard’ of presenting and explaining contents to students. In the following five different approaches are described to investigate teachers’ PCK trying to solve some of the above problems.

The following papers introduce their work based on both different backgrounds and approaches to measure this important part of professional knowledge. The measurement of PCK is presented regarding biology, technology and physics content for primary and secondary school teachers as well as pre-service teachers and students. Additionally advantages and disadvantages of open-ended and multiple choice items and their analysis are discussed.
MEASURING PRIMARY SCHOOL TEACHERS’ PEDAGOGICAL CONTENT KNOWLEDGE IN TECHNOLOGY EDUCATION WITH A MULTIPLE CHOICE TEST

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Abstract

Pedagogical content knowledge (PCK) is a crucial part of a teacher’s knowledge base for teaching. Studies in the field of technology education for primary schools showed that this domain of teacher knowledge is related to pupils’ increased learning, motivation, and interest. The common methods to investigate teachers’ PCK are often complicated, and time and labour consuming. Hence, a challenge in measuring teachers’ PCK is to construct an instrument that is time and labour-efficient, and makes it possible to investigate large sample sizes. This paper illustrates how a multiple choice test to measure teachers’ PCK in primary technology education was designed and validated. The procedure of test construction and results related to the validation of the test are presented. It is concluded that the systematic procedure that was followed is effective for the construction of a valid test. Statistical analyses showed that test-retest reliability as well as convergent validity of the test is satisfying. Despite the heterogeneity of the construct, measurement of PCK with a multiple choice test has clear-cut advantages compared to qualitative methods.

Introduction

Teacher knowledge is a popular theme for investigation in the field of science education. Research in this domain has produced valuable insights into science teaching. In this paper, we focus on pedagogical content knowledge (PCK), which is considered to be a distinctive domain of teacher knowledge, in the field of primary technology education. In this specific field, PCK is still rather unexplored. Since science and technology are strongly interrelated subjects, results in both fields are expected to be interchangeable to a large extent.

The American educationalist Lee Shulman introduced the term ‘pedagogical content knowledge’ when he investigated the knowledge base of teachers. He defined it as “a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding” (Shulman, 1987, p. 8). He stated that effective teachers need PCK rather than just knowledge of a particular subject matter.

Van Driel, Verloop, and De Vos (1998) compared conceptualizations of PCK used by different researchers. They showed that there is no universally accepted conceptualization, but that all researchers agree on two essential aspects: (1) understanding of pupils’ specific learning difficulties and (2) knowledge of representations of the subject matter to overcome these difficulties. Most researchers in science education that study PCK seemed to build upon...
Shulman’s definition of PCK. Furthermore, Van Driel, Verloop, and De Vos (1998) illustrated that researchers assumed subject matter knowledge to be a prerequisite for the development of PCK.

The New Zealand researchers (Jones & Moreland, 2004), who investigated PCK in primary technology education, found that enhanced PCK is positively related to pupils’ learning, motivation, and interest in technology. PCK is therefore considered to be the most crucial domains of teacher knowledge (e.g., Grossman, 1990; Jones, Harlow, & Cowie, 2004; Magnusson, Krajcik, & Borko, 1999; Shulman, 1987; Van Driel et al., 1998).

In order to define PCK in the context of this study, three aspects that are assumed to be essential for effective technology education were derived from scientific literature on PCK: (1) knowledge of pupils’ concept of technology, and knowledge of pupils’ pre and misconceptions related to technology, (2) knowledge of pedagogical approaches and teaching strategies for technology education, and (3) knowledge about the nature and purpose of technology education (Rohaan, Taconis, & Jochems, 2008).

The central aim of the presented studies was to explore the possibility to measure teachers’ PCK of technology education for primary schools with a multiple choice test. This paper shows how a multiple choice test was designed and validated.

Rationale

Most researchers (e.g., De Jong, Van Driel, & Verloop, 2005; Jones & Moreland, 2004; Mulholland & Wallace, 2005; Van Driel et al., 1998) who investigated PCK used multimethod evaluations, that is, a variety of techniques which typically includes structured, semi-structured or stimulated recall interviews, observations, and concept mapping. Data from these different sources are triangulated, which results usually in a general profile of a teacher’s PCK (Baxter & Lederman, 1999).

The methodologies and techniques currently used to measure PCK require teachers to be strongly involved in the research project, and are often labour-intensive and time-consuming. Furthermore, quality indicators of multimethod evaluations of PCK are hardly available, which makes comparison between the methods difficult. Hence, the challenge in examining PCK remains to construct an instrument that requires less teacher involvement, measures PCK in a time and labour-efficient way, and makes it possible to investigate large sample sizes. In our view, the best way to achieve this is by constructing a multiple choice test.

Methods

To construct our multiple choice test, we used the ‘rational method’ (or ‘content-oriented method’) of test construction (Oosterveld & Vorst, 1996). This method is classified as ‘intuitive’ and focuses on optimizing content validity. Rather than empirical data, judgments of experts are of particular importance for the specification and construction of items. This method is found to be especially useful if the central concept is conceptualized insufficiently and if empirical data are scarce. Both of these features apply to PCK in primary technology education, which made the choice for this method of test construction a valid choice.

The procedure of test construction can be chronologically divided into seven phases: (1) specification of the theoretical framework, (2) construct analysis, (3) specification of item characteristics, (4) production of items, (5) judgement of items, (6) construction of the instrument, and (7) validation of the instrument. According to the rational method, specifying the theoretical framework means creating a shared view of the construct, usually in the form of a working definition. The construct is analyzed by describing typical phenomena or situations, which are often used as item scenarios or contexts. It is of particular importance that the experts agree on the working definition. The items are judged by the experts and their judgements form the foundation of the test construction. The test is validated by comparing the results with the experts’ judgements (Oosterveld & Vorst, 1996).
Our expert team (7 members) had four successive meetings (each meeting lasting approximately 4 hours), which were led by the test constructor. After the last meeting, the test constructor compiled the first complete instrument, called the ‘Teaching of Technology Test’ (TTT). Altogether, 52 items were produced and judged and 40 of these items were selected for the test (see Figure 1 for an item example). Because 40 items in one test would make the test too long for administration, it was divided in two equal parts (A and B).

Figure 1. Item example of the Teaching of Technology Test (TTT).

With the intention to determine the convergent validity of the TTT, teachers’ content knowledge of technology was measured with the Cito technology test (Weerden, Thijssen, & Verhelst, 2003). This test measures factual, or descriptive, knowledge and is originally designed to use with primary school pupils in the end of the sixth (last) grade, but turned out to be useful with primary school teachers as well. The Cito technology test is a multiple choice test that contains 48 items with 3 to 4 answer alternatives. Reliability (Cronbach’s alpha) was found to be 0.79 for the present sample (n=361).

With the same intention, the Personal Science Teaching Efficacy Belief (PSTE) scale of the Science Teaching Efficacy Belief Instrument (STEBI) was used to measure self-efficacy in technology teaching. We adapted the STEBI from Bleicher (2004), which is a modification from the original by Enochs and Riggs (1990), translated it into Dutch and slightly revised it to fit the context of technology education. The scale contains 13 items with a 5 point Likert scale. Reliability (Cronbach’s alpha) was found to be 0.91 for the present sample (n=354).

Results

First study

The two versions of the TTT (A and B) were sent to approximately 120 primary schools, which were involved in a governmental project on primary technology education in the Netherlands. The distribution of the tests was done by e-mail. In total, 34 teachers filled out and returned the test. All subjects were primary school teachers in (Dutch) grade 6, 7 and/or 8 (pupils’ age 9-12 years). Version A was completed by 21 teachers (14 male and 7 female) and version B by 13 teachers (7 male and 6 female). Their mean age was 43 years (sd=11) and their
mean teaching experience 20 years (sd=12). A refresher course on technology education was recently completed by 47.1\% of the teachers in the sample. For each subject a PCK score was computed simply by counting all the ‘high PCK’ alternatives that were chosen by the subject (divided by the number of items and multiplied by 10). For version A the mean PCK score was 4.89, for version B this mean score was 5.91. On each version the male teachers scored higher than the female teachers, but these differences were not statistically significant.

The analysis of the data mainly served as a statistical exploration in order to make a first, well-considered selection of items. Three basic selection criteria were applied, that is, validity, reliability, and discriminating power. After a descriptive analysis of the items, three items (1 of version A and 2 of version B) were excluded from further analysis based on the absence of variance in responses, that is, all subjects chose the same alternative.

To detect meaningful underlying dimensions and support the reliability of the response alternatives, Multidimensional Scaling (MDS) analysis was performed, using a dichotomous score (0 or 1) for each of the alternatives. MDS analysis was appropriate because of a meaningful rank ordering of the response alternatives. The four answer alternatives were characterized beforehand as representing ‘high PCK’, ‘low PCK’, pedagogical knowledge, or content knowledge (‘no PCK’). A three-dimensional MDS analysis of the response alternatives fitted the data in a useful and interpretable way. The 3D scatter plots revealed a distribution of the categories roughly as expected, that is, a cluster of ‘high PCK’ alternatives opposite to a cluster of ‘no PCK’ alternatives (pedagogical and content knowledge) and the ‘low PCK’ alternatives spread in between. Based on rotatable 3D plots, the outliers in the group of ‘high PCK’ alternatives were traced and the corresponding items were excluded.

The next steps in the item selection procedure were undertaken alternately to create an iterative approach towards a first, rudimentary scale definition. Cronbach’s alpha was calculated to determine internal consistency of the scale. Convergent validity was assessed by using the indicator ‘having completed a refresher course on technology education’. The PCK score of version A correlated significantly with completion of a refresher course (version A: rs=0.448, p <0.05; version B: rs=0.503, n.s.) in the expected direction. In order to make sure that the test would be a mixture of easy as well as difficult items, the discriminating power of the test items were analyzed by comparing mean item scores between groups with high (>5) and low (<5) teaching technology experience. After this item selection procedure version A included 9 items (α=0.60) and version B included 10 items (α=0.49).

Second study

In a follow-up study, the merged TTT (19 items) was administered by means of an online questionnaire system to a larger group (n=101) of primary school teachers, who (93\%) taught pupils’ in the age of 8 to 12 years (Dutch grades 5 to 8) in the Netherlands. The sample consisted of 57 male and 44 female teachers, with a mean age of 44 years. Of these teachers 70.3\% had more than 10 years of teaching experience. A refresher course on technology education was completed by 23.8\% of the teachers in the sample. In this study, the mean PCK score on the TTT was 4.61, on a scale from 1 to 10. Again, no statistically significant difference was found between male and female teachers. A positive and significant correlation between the TTT score and completion of a refresher course on technology education was found (rs=0.166, p<0.05).

Internal consistency of the test was found to be rather low (Cronbach's alpha is 0.36 for all 19 items, and 0.46 for 15 items with positive item-total correlations). A factor analysis with oblique rotation showed that the test had multiple dimensions (6 dimensions with eigenvalue >1), but these dimensions could not be interpreted in a meaningful way. Multi-dimensionality was also confirmed by low item-total correlations and high variance in item scores.

However, in case of a heterogeneous construct, such as PCK, Cronbach’s alpha is a strict lower bound to reliability and is a poor measure for consistency of the scale (Lucke, 2005). As an alternative, test-retest reliability was calculated by comparing the scores of 10 teachers who filled out the TTT during the first study (May 2007) and
again during the second study (March 2008). The test and retest scores correlated significantly ($r=0.641$, $p<0.05$), which means that the test is moderately reliable over time.

Third study

A large scale validation study was carried out with a sample of 397 primary school teachers (39.2% male and 60.8% female) in the Netherlands. Their mean age was 42.5 years (sd=11.9), their mean years of teaching experience 17.7 years (sd=12.1), and their mean years of technology teaching experience 4.4 years (sd=6.8). Most teachers (88.7%) in the sample taught in the upper grades (3-6) of primary education.

Regarding the distribution of TTT scores, skewness was found to be slightly negative (-0.11, left skewed), but still within the norms of a normal (Gaussian) distribution. The mean test score was 5.76 (sd=1.19) on a scale from 1 to 10. The difficulty values (i.e., proportion of correct items) were evenly distributed among the items, with a lowest value of 0.16 and a highest of 0.71 (10 items with difficulty value <0.50 and 8 items with difficulty value >0.50). Test-retest reliability was calculated by correlating the test scores of both administrations (October/November 2008 and March 2009). Pearson’s correlation coefficient was found to be 0.622 ($p<0.01$, $n=31$).

In order to examine the convergent validity of the TTT, correlations with test scores on the Cito technology test and STEBI (PSTE scale) were calculated. The correlation coefficient between the TTT score and the Cito score was significant and positive, but small ($r=0.153$, $p<0.01$). The same applies for the correlation between the TTT score and the STEBI score ($r=0.208$, $p<0.01$). These correlations coefficients were expected to be small, because both the Cito and the STEBI measure different constructs (respectively, content knowledge and self-efficacy) compared to the TTT (PCK). Besides, low internal consistency of the TTT causes an attenuation effect that weakens the correlation. The correlations coefficients after correction for attenuation are respectively 0.401 (medium) and 0.239 (small).

Conclusions and Implications

The aim of this study was to explore the possibility to construct and validate a multiple choice test that measures primary teachers’ PCK in technology education.

The rational method of test construction was strictly followed and completed with statistical analyses, which made the entire construction procedure solid and systematic. Experts in the field of primary technology education agreed on the items measuring PCK in technology, which means that content validity of the test can be depicted as being high. Nonetheless, several issues arose during test construction, which were hard to solve. Regarding the production of items, it was found difficult to formulate the best answer and plausible distracters. The experts struggled with writing best answer alternatives that reflected integration of content knowledge and pedagogical knowledge as well. However, we conclude that the procedure followed to construct our multiple choice test to measure teachers’ PCK of primary technology education is proved to be effective.

The statistical results concerning internal consistency and multi-dimensionality are in line with the heterogeneous nature of PCK, which is reported by various researchers (e.g., Cochran, Deruiter, & King, 1993; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Magnusson et al., 1999; Van Driel et al., 1998). PCK is a construct that is comprised of different aspects at different levels, which are tightly connected and cooperate as a whole. It is undesirable to artificially isolate these aspects in a single test or test item, because this creates an unrealistic representation of PCK (lower validity). We conclude that it is possible to statistically validate a PCK test when focusing on test-retest reliability.
With regard to the validity of the TTT, we conclude that the instrument is valid in terms of convergent and content validity. As expected from literature on PCK in science education (Park & Oliver, 2008; Van Driel et al., 1998), the test scores correlated significantly with the scores on tests that measure content knowledge and self-efficacy. Regarding content validity, the experts who wrote and judged the items all agreed on the selection of items that form the test. Concerning the reliability of the test, Cronbach’s alpha was found to be low, both for the three subscales as for the overall scale. However, the low alpha’s could be explained by the heterogeneous nature of the measured construct, PCK. Besides, calculation of test-retest reliability showed that the test is satisfactory consistent over time.

This study indicates that measuring PCK with a multiple choice test is complicated, though not impossible. The exploration of a new measurement instrument for PCK has scientific as well as practical implications. First, this method of PCK measurement sheds a new light on the concept of PCK and contributes to the conceptualization of the construct. Moreover, it allows researchers to easily examine large sample sizes. However, to measure PCK more profoundly, it is still strongly recommended to complement these kinds of measurement instruments with interviews, observations, or other qualitative methods that examine teachers’ PCK. Insights into teachers’ PCK are expected to improve the efficiency and quality of technology education.
PEDAGOGICAL CONTENT KNOWLEDGE IN SCIENCE EDUCATION
WITH OPEN-ENDED AND MULTIPLE-CHOICE ITEMS

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Abstract
Pedagogical content knowledge (PCK) has become a central component of teachers’ professional knowledge. Studies in the field of mathematical education for primary and secondary schools directly assessed PCK and showed that this domain of teacher knowledge is related to an increase in pupils’ learning outcomes. In the field of science education research has mostly drawn on distal indicators to assess PCK. So direct measures that allow statistical analysis are rare in science education and are missing completely in the domain of primary science. To address this research gap this article presents the theory-based construction of a test to assess primary science teachers’ PCK drawing on the work of Shulman (1986) and Magnusson et al. (1999). The test was piloted (N=115) and implemented in the PLUS-study (prelim. N=107). Preliminary analyses of the psychometric properties are reported and indicate that the test construction can be considered successful in terms of objectivity and reliability.

Introduction
The study presented here is part of a dissertational project embedded in the project PLUS that investigates conditions and outcomes of science teaching in transition from primary to secondary school in Germany. The scope of the dissertational project is to explore whether and how teachers’ pedagogical content knowledge (PCK) in science contributes to gains in students’ understanding of scientific concepts. For this paper the focus lies on the development of a paper-and-pencil instrument with open-ended and multiple-choice items to measure PCK of German primary teachers in science.

Rationale
Pedagogical content knowledge is considered a central component of teachers’ professional knowledge (Grossman, 1990; Shulman, 1987; Van Driel, Verloop, & De Vos, 1998). However, most research on teacher knowledge has been based on rather distal indicators such as university grades, number of subject matter courses taken at university, or questionnaire data on beliefs or subjective theories (Hill, Rowan, & Ball, 2005; Pajares, 1992). As a consequence the precise nature, content, structure, and quality of this knowledge remain uncertain. Only recent studies in the domain of mathematics education introduced direct measures of pedagogical content knowledge (Hill, Schilling, & Ball, 2004; Krauss et al., 2008). These approaches can be embedded within Shulman’s (1986, 1987) taxonomy of teacher knowledge.
Shulman (1986) has presented the concept of PCK within a classification of components of teachers’ professional knowledge. PCK is described as a kind of ‘amalgam’ of content knowledge with pedagogical and psychological knowledge as well as with the teacher's personal experiences, creating an understanding of how certain topics, problems or issues ought to be presented and adapted to the learners’ different interests and abilities (Bromme, 1997; Shulman, 1987). In this research tradition Magnusson et al. (1999) also proposed a model of PCK in the area of science education, defining five components to classify PCK. They include ‘orientations towards science teaching’, ‘knowledge of science curricula’, ‘knowledge of students’ understanding of science’, ‘knowledge of instructional strategies’ and ‘knowledge of assessment for science’. Recent studies on the different domains of PCK (e.g. orientations towards teaching, knowledge of student understanding or instructional strategies) in mathematics presented remarkable research by finding that teachers’ mathematical pedagogical content knowledge was positively related to student gains in mathematical achievement (e.g. Brunner et al., 2006; Hill, Rowan, & Ball, 2005; Peterson, Fennema, Carpenter, & Loef, 1989; Staub & Stern, 2002). Whereas studies in the domain of orientations towards teaching have already been established in the field of primary science (Kleickmann, 2008), studies targeting at the further components of PCK in science are rather rare and are missing completely in primary science. Thus, in order to address this research gap, an instrument has to be developed, that captures primary science teachers PCK.

Methods

The assessment of teachers’ PCK is based on the Magnusson et al. model (1999) mentioned above. Considering the recent studies in mathematics that described ‘knowledge of student understanding’ and ‘knowledge of instructional strategies’ as components of PCK that trigger student achievement, the main focus of the test will be nested within these two components (Brunner et al., 2006; Hill, Rowan, & Ball, 2005). Multiple-choice and mostly free response items for a paper-and-pencil-test measuring the two selected domains were developed. The test was given to a sample of 115 teachers in a pilot study and then conducted to our main study of preliminary 107 teachers. We assessed “knowledge of students’ understanding” for example by testing teachers’ awareness of students’ alternative conceptions and areas of student difficulties. “Knowledge of instructional strategies” was assessed by items requiring teachers to provide useful representations, experiments or examples to promote insightful learning. All items were scored as correct or false according to a coding manual. Relevant solutions were drawn from empirical studies and theories in science teaching and learning and established by experts. For the majority of the items each category of a correct answer in a teacher’s response was scored 1. For items requiring several answers the sum of the correct answers was calculated. For some items this aggregation of right categories did not seem adequate. In these cases the answers were rated in comparison to a master-answer.

Results

To give a first impression of measurement quality, we report the psychometric properties of the PCK-test, which were analyzed by classical test theory. All items of 25 randomly drawn questionnaires from the pilot-study were coded by two independent raters. The intraclass correlation as a measure of interrater reliability for the free-response-items was nearly perfect (on average .93 with a min. of .84 and a max. of 1.0). Furthermore the test yielded satisfactory reliabilities. The final test consists of 16 items (13 free-response-, 3 multiple-choice-items) with a reliability of Cronbach’s \( \alpha = 0.71 \). Although first aspects of validity have been explored in terms of face and construct validity (comparison of PCK score with external criteria also obtained within the main study of the PLUS-project), further investigations need to be made.
Conclusions and Implications

The first research aim was to construct a test that measures primary teachers' PCK in science education directly. Whereas distal indicators or self-report data are commonly used to assess teachers’ competences the presented results indicate that we succeeded in developing a reliable direct assessment tool for primary science teachers’ PCK that shows good psychometrical qualities. Such a test is need for further research questions like exploring the impact of PCK on students’ achievement gains or to evaluate the effectiveness of teacher trainings. If, in further analyses, we are able to show that primary science teachers' PCK positively predicts student gains in science achievement our results will provide support for initiatives designed to improve teacher education and in-service-training. Since studies have shown that teacher knowledge can be changed (Richardson & Placier, 2001) through courses it might be possible to improve students’ achievement in science by improving teachers PCK through pre-service and in-service programs. The developed paper-and-pencil-test could serve as a conceptual and analytic tool for examining whether and what teachers learn from specific programs.
MEASURING DECLARATIVE AND REFLECTIVE COMPONENTS OF BIOLOGY TEACHERS’ PEDAGOGICAL CONTENT KNOWLEDGE

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Abstract

One central component of science teachers’ professional knowledge besides pedagogical knowledge and content knowledge is pedagogical content knowledge (PCK). Science teachers’ PCK includes knowledge of students’ pre- and misconceptions, knowledge of curriculum and nature of a subject, as well as knowledge of science teaching strategies. These three categories are represented by two different types of knowledge: ‘PCK-in-action’ and ‘PCK-on-action’. ‘PCK-in-action’ describes implicit and procedural knowledge (skills). ‘PCK-on-action’ describes explicit and declarative knowledge. To integrate ‘PCK-in-action’ and ‘PCK-on-action’ some researchers assume reflective components of teachers’ PCK to be important. For an empirically validation of current conceptualisations of PCK, valid and reliable instruments are needed. This study presents such an inventory for measuring declarative and reflective components of biology teachers’ PCK. The inventory has been developed as a video clip supported paper-pencil test and has been proven for psychometrical quality criteria with pre- and in-service biology teachers. Within the scope of the results item samples and psychometrical quality criteria of the inventory are presented. The developed inventory can be used for evaluation of biology teacher training programs. Furthermore, the developed video clips can be used to activate biology teachers’ inert PCK or to discuss quality of implementation of science teaching strategies (‘PCK-in-action’).

Introduction

One central component of science teachers’ professional knowledge which appears in various conceptualisations is pedagogical content knowledge (=PCK; Abell, 2007; Baumert & Kunter, 2006; Cocharan, King, & De Ruiter, 1993; Gess-Newsome & Lederman, 1999; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Shulman, 1986; 1987). The concept of PCK was introduced by Shulman (1986; 1987) in the mid-eighties. PCK embraces the idea that teachers have a special notion of content and pedagogy which they draw on in teaching a topic. In this regard, PCK describes teachers’ knowledge of how to support students in understanding specific subject matters.

Since the introduction by Shulman (1986, 1987), PCK has become a useful and frequently used concept for research on instructional quality as well as research on teachers’ professional knowledge. Within the research on instructional quality, current studies focus not only on classroom criteria (‘process-product paradigm’; Abell, 2007), but also on teachers’ characteristics. In this context for example the LMT-study (Learning Mathematics for Teaching; Hill, Rowan, & Ball, 2005) and the COACTIV-study (COACTIV: Cognitive Activation in the Classroom: The Orchestration of Learning Opportunities for the Enhancement of Insightful Learning in Mathematics; Krauss et al., 2008) showed that mathematic teachers’ PCK is a good predictor for students’ achievement as well as for quality of instruction in mathematic lessons (especially for cognitive activation). In addition, research on teachers’ professional knowledge focuses on the development, training, and evaluation of science teachers’ PCK. This research tradition assumes
teachers’ reflection, teaching experience and teacher training programs to be important promoters to foster science teachers’ PCK (De Jong & Van Driel, 2004; Grossman, 1990; Nilsson, 2008; Park & Oliver, 2008; Van Driel, Verloop, & de Vos, 1998; Van Driel, De Jong, & Verloop, 2002).

Both research on instructional quality and research on teachers’ professional knowledge agree that science teachers’ PCK is a dynamic and topic specific knowledge which consists of three central categories: knowledge of (I) students and students’ pre- and misconceptions, (II) knowledge of representations, illustrations and science teaching strategies, and (III) knowledge of the curriculum, nature and purpose of a subject (Baumert & Kunter, 2006; Park & Oliver, 2008; Van Driel et al., 1998, 2002). These three categories are represented by two different types of knowledge: ‘PCK-in-action’ and ‘PCK-on-action’ (Baumert & Kunter, 2006; Park & Oliver., 2008; Tamir, 1989). ‘PCK-in-action’ describes implicit, procedural knowledge and skills (knowing how…). ‘PCK-on-action’ can be described as formal-theoretical, explicit and declarative knowledge (knowing that…). To integrate ‘PCK-in-action’ and ‘PCK-on-action’, reflective components (‘reflection-in-action’; ‘reflection-on-action’; Schön, 1983) of science teachers’ PCK are important (Park & Oliver, 2008). Reflection allows the evaluation and analysis of ‘PCK-in-action’. Hence, reflection is necessary for proofing, correcting and improving teachers’ ‘PCK-in-action’. Additionally, reflected ‘PCK-in-action’ generates teaching experience, which leads to an increase of ‘PCK-in-action’. As a result, reflection-in-action and reflection-on-action synergistically impact PCK growth in terms of knowledge-in-action and knowledge-on-action. “… PCK has both aspects of knowledge-in-action and knowledge-on-action. The two aspects were not mutually exclusive, but rather influenced each other through reflection, either inside or outside classrooms. As a result, reflection-in-action and reflection-on-action synergistically impact PCK growth in terms of knowledge-in-action and knowledge-on-action.” (Park & Oliver, 2008, p. 270).

![Figure 1: Relation of ‘PCK-on-action’, reflection and ‘PCK-in-action’.](image)

**Rationale**

To investigate and evaluate biology teachers’ PCK as well as to empirically validate current PCK conceptualisations - in particular hypothetical correlations between ‘PCK-on-action’, reflection and ‘PCK-in-action’ - reliable and valid instruments would be helpful. Regarding the lack of standardized, reliable and valid PCK instruments for biology teachers in Germany the presented study aims to develop and evaluate an inventory for measuring biology teachers’ PCK concerning the topic ‘blood and human cardiovascular system’. Therefore, the research aims are:

I. Development and evaluation of an instrument to measure declarative components of biology teachers’ PCK (‘PCK-on-action’).

II. Development and evaluation of an instrument to measure reflective components of biology teachers’ PCK.

**Methods**

In a first step we developed the instrument to measure declarative components of biology teachers’ PCK. Then we used it with a pilot sample of pre- and in-service biology teachers. In a second step we developed the instrument to measure reflective components of biology teachers’ PCK and also used it with a pilot sample of pre-service biology teachers.
Development and evaluation of an instrument to measure declarative components of biology teachers’ PCK

**Development of items and scales for measuring declarative components of biology teachers’ PCK**

To develop an instrument for measuring declarative components of biology teachers’ PCK (‘PCK-on-action’), we designed a paper and pencil test with open-ended items concerning the topic ‘blood and human cardiovascular system’. Literature as well as further studies showed that open-ended items are a promising way to measure teachers’ PCK (Baxter & Lederman, 1999; Hill, Loewenberg-Ball, Schilling, 2008; Krauss et al., 2008; Kromrey & Renfrow, 1991). In contrast to open-ended items, the use of multiple choice items would cause problems with the participants’ identification of answer alternatives (‘Aha-effect’; Hill, Loewenberg-Ball, Schilling, 2008) as well as problems concerning social desirability (‘social desirability bias’; Fisher, 1993). Furthermore, multiple choice items presume to judge between a ‘right’ and ‘wrong’ response, but in pedagogy it is hard to set a ‘best practice’, because of multiple normative goals and a lack of empirical evidence in educational sciences (Kromrey & Renfrow, 1991).

The item construction referred to three test scales: (I) knowledge of subject & curriculum, (II) knowledge of students and students’ cognitions and (III) knowledge of science teaching strategies and was supported by in-service biology teachers. The items e.g. demand the participant to list as many students’ pre- and misconceptions as possible concerning a biological phenomenon, representation or model. To score the open-ended items in an objective manner a coding manual was developed. For validating the instrument we checked literature on biology education as well as on students’ pre- and misconceptions concerning the topic ‘blood and human cardiovascular system’; Loughran, Milroy, Berry, Gunstone & Mulhall, 2006; Sungur, Tekkaya & Geban, 2001). The developed items respectively scales were used in a first pilot study with pre-service and in-service biology teachers to evaluate them on psychometric test criteria.

**Pilot testing of items and scales for measuring declarative components of biology teachers’ PCK**

The items and scales for measuring declarative components of biology teachers’ PCK were tested with a random sample of pre- and in-service biology teachers (N = 50) of all school forms and all grades in North Rhine-Westphalia (Federal State of Germany). The gained data was used to evaluate the internal consistency of the developed test scales as well as the test difficulty and the inter-rater reliability of the developed coding manual. All of the participating pre-service biology teachers were situated in their main studies at one university. The participating in-service (N = 32) biology teachers’ mean teaching experience was 10.5 years (M = 10.5; SD = 11.25). 14% of the in-service biology teachers had a teaching degree for lower-secondary schools, 10% had a teaching degree for upper-secondary schools, 76% had a teaching degree for both lower and upper-secondary schools.

Development and evaluation of an instrument to measure declarative components of biology teachers’ PCK

**Development of items and scales for measuring reflective components of biology teachers’ PCK**

Concerning the development of an instrument for measuring reflective components of biology teachers’ PCK we used fictional video clips to initialize participants’ reflection. The decision to use fictional video clips is supported by four arguments: The first argument is that fictional video clips focus all participants’ reflection on the same standardized teaching situation (standardized reflection). The second argument is, that fictional video clips combined with pedagogical context information on curriculum, learning group, and learning goals enable all participants to get the same information and preconditions (standardized preconditions). Thirdly, fictional video clips prevent problems with a biased self-perception as it would be the case with self-reflection. Fourthly, fictional video clips are more test economic compared to a time- and money-consuming individual video taping of every single participant.
According to the four arguments mentioned above we videotaped fictional biology instruction acted by two 9th grade biology classes. The video clips focus on critical situations of the treatment of biological contents in pedagogical situations referring to the topic ‘blood and human cardiovascular system’. That way we constructed short video clips (2-3 minutes) showing PCK relevant teaching situations (e.g. response to students’ pre- and misconceptions; use of models, use of experiments) which can be used to initialize teacher reflection. For a better understanding of the video clips we added subtitles. Additionally, the video clips are accompanied by fictional pedagogical context information (called ‘info boxes’) which include information on learning group (pre-knowledge, grade), curriculum (topic), learning materials (e.g. working sheets) and intended learning goals.

The video clips were documented on a DVD. An accompanying paper and pencil test includes the developed ‘info boxes’ as well as the developed open-ended items. The scales which were designed to measure reflective components of biology teachers’ PCK are: (I) observation and shift of attention, (II) evaluation and (III) analysis of PCK relevant teaching situations. In a first pilot study the video clips were validated by the means of an expert rating by in-service biology teachers. Then we conducted a first pilot study to evaluate the developed instrument with pre-service biology teachers on psychometric test criteria.

Validation of video clips and pilot testing of items and scales for measuring reflective components of biology teachers’ PCK

To analyze validity of the developed video clips we conducted an expert rating on a five step Likert scale (three items; validity \( \text{min} = 1 \); validity \( \text{max} = 5 \)) with a random sample of in-service biology teachers \( (N = 34) \). The sample consisted of in-service biology teachers of all school forms (Gymnasium, Realschule, Hauptschule & Gesamtschule) and all grades in North Rhine-Westphalia (Federal State of Germany). The mean of teaching experience of the in-service biology teachers was 14.3 years \( (M = 14.3; SD = 11.7) \). 35% of the in-service biology teachers had a teaching degree for lower-secondary schools, 5% had a teaching degree for upper-secondary schools, 40% had a teaching degree for both lower and upper-secondary schools. 20% of the participants did not state their degree.

After evaluating and validating the video clips with in service-biology teachers, the instrument (consisting of a DVD with six selected video clips which is accompanied by a paper pencil test with open-ended items) was used in a pilot study with pre-service biology teachers \( (N = 23) \) of two universities from North Rhine-Westphalia and Bavaria (Federal States of Germany). Again, the validity of the video clips was evaluated with a five step Likert scale (three items; validity \( \text{min} = 1 \); validity \( \text{max} = 5 \)). The pre-service biology teachers were in their main studies or had already finished their university level of biology teacher education. All of them already visited a practical course in biology lessons.

Results

Evaluation of items and scales for measuring declarative components of biology teachers’ PCK

The developed open-ended items \( (N = 40) \) contain pedagogical context information on students (grade & pre-knowledge), intended learning goals and curricular content. Additionally, the item task is formulated as a problem of a trainee teacher. That way we intended to put the participant in the position of an expert (fig. 2).
A trainee teacher plans to use the model/representation shown below to introduce the human circulatory system in his 9th grade. His students already know the elements and functions of blood. He asks you for your advice. Which students’ misconceptions could arise if he does not explain the representation shown below? Please state as many student misconceptions as you know!

Illustration available under: www.transplant-forum.de/uploads/tx_templavoila/blutkreislauf_kl_neu.png

Figure 2: Item sample for measuring declarative components of biology teachers’ PCK on experiments.

Results of the pilot study with pre- and in-service biology teachers (N = 50) showed a satisfying internal consistency of the developed instrument (α = .86) and its three sub scales (α = .72 - .82; table 1). Hence, the instrument can be seen as reliable.

**Table 1: Reliability of scales for measuring biology teachers’ declarative PCK (N = 47).**

<table>
<thead>
<tr>
<th>Scales</th>
<th>Items</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I) Content &amp; curriculum</td>
<td>6</td>
<td>.72</td>
</tr>
<tr>
<td>(II) Students’ cognitions (pre- and misconceptions)</td>
<td>12</td>
<td>.73</td>
</tr>
<tr>
<td>(III) Pedagogical approaches and science teaching strategies</td>
<td>22</td>
<td>.82</td>
</tr>
<tr>
<td>Overall test reliability</td>
<td>40</td>
<td>.86</td>
</tr>
</tbody>
</table>

The developed coding manual has been proven on inter-rater reliability via intra-class correlation (ICC) which shows an acceptable inter-rater agreement for 20% of the sample size evaluated by two independent raters (ICC UNJUST, TWO FACTORS = .77; F(9,9) = 7.50; p = .003). The scoring of the open-ended items with the developed coding manual can be seen as objective. A t-test was used to compare the mean test score of pre-service and in-service biology teachers. That way, we wanted to empirically validate our instrument. A significant higher score of in-service biology teachers compared to pre-service biology teachers could be a hint for actually measuring PCK. The pre-service biology teachers showed a significant lower test score compared to in-service biology teachers (T(25) = 4.58; p < .001). Additionally, the achieved total marks were evaluated on normal distribution via Kolmogorov-Smirnov-Test. The total marks respectively the test difficulty was normal distributed (D (31) = .436; p = .991).

Evaluation of items and scales for measuring reflective components of biology teachers’ PCK

An expert rating on a multiple item Likert scale (five stages: validity_{min} = 1; validity_{max} = 5) with in-service biology teachers (N = 34) confirmed a high validity of the developed video clips (α = .90; M = 3.79, SD = .92). This appraisement was replicated by a rating of validity of video clips by pre-service biology teachers (N = 23; α = .70; M = 3.9, SD = .67). Furthermore, 64% of the in-service biology teachers reported to prefer a video based lesson vignette compared to a classical written lesson vignette.

The developed items (N = 18) demand the observation, evaluation and analysis of video clips (fig. 3, fig. 4). Results of the pilot study with pre-service biology teachers (N = 23) showed that reliability of scales is acceptable (α = .61 - .74; table 2). To proof objectivity, the coding manual for item scoring has been checked for inter-rater reliability for 20% of the tests, evaluated via intra-class correlation (ICC) which shows a very high inter-rater agreement (ICC UNJUST, TWO FACTORS = .90; F(5,5) = 18.8; p = .003). The achieved total marks were evaluated on normal distribution via Kolmogorov-Smirnov-Test. The test difficulty is normal distributed for all three scales (D_I (21) = .628; p = .825; D_II (21) = .956; p = .320; D_III (21) = .778; p = .580).
Figure 3: Screenshots of the DVD and a video clip.

Table 2: Reliability of scales for measuring reflective components of biology teachers’ PCK (N = 23).

<table>
<thead>
<tr>
<th>Scales</th>
<th>Items</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I) Observation and shift of attention</td>
<td>6</td>
<td>.73</td>
</tr>
<tr>
<td>(II) Evaluation of PCK relevant teaching situations</td>
<td>6</td>
<td>.61</td>
</tr>
<tr>
<td>(III) Analysis of PCK relevant teaching situations</td>
<td>6</td>
<td>.74</td>
</tr>
</tbody>
</table>

Conclusions and Implications

The evaluation of instruments confirms a reliable and objective first approach on measuring central components of biology teachers’ PCK. The developed video clip supported instrument seems to be a promising approach to measure reflective components of PCK in an integrated and valid way. As a critical point concerning the instruments, a possible motivation bias should be discussed. As the test scores mostly relies on the number of given answers (the items e.g. demand the participant to list as many students’ pre- and misconceptions as possible concerning a biological phenomenon, representation or model) the motivation of the participants could have an effect on the number of given answers.

In a next step we will empirically validate the whole inventory by using it not only with biology teachers but also with biologists (experts on content knowledge) and non-biology teachers (experts on pedagogical knowledge). That way we want to proof the validity of our operationalisation of biology teachers’ PCK and if the test score of both instruments does not derive from biology teachers’ content knowledge or pedagogical knowledge (discriminate validity check). Furthermore, we will evaluate both instruments with a bigger sample size of pre-service and in-service biology teachers (N = 100).
Within the context of biology teacher education the instruments can be used for quality assurance as well as for biology teacher certification in the field of ‘blood and human cardiovascular system’. Furthermore, the developed items and video clips can be used as learning material for biology teacher training programs. The video clips could help identifying biology teachers’ inert pedagogical content knowledge and support discussions about quality of instruction in biology lessons respectively quality of implementation of science teaching strategies. Additionally, the video clips could be utilized as an initial point to train biology teachers’ reflection abilities.

Within research on biology teachers’ professional knowledge the inventory can be used to validate different conceptualisations of teachers’ professional knowledge in an empirical manner as well as to investigate the development of various components of biology teachers’ PCK in the frame of biology teacher education.

In the context of research on instructional quality the inventory can be applied together with instruments on quality of instruction in biology lessons to investigate the relation of biology teachers’ PCK and quality of instruction in biology lessons respectively students’ learning achievement.
MEASURING PHYSICS STUDENT TEACHERS’ PEDAGOGICAL CONTENT KNOWLEDGE AS AN INDICATOR OF THEIR PROFESSIONAL ACTION COMPETENCE

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Abstract
In recent years, disappointing results of large scale assessments like PISA have led to a rising interest in what are important aspects of professional action competence of (physics-) teachers and how they develop. Against this background there is a lack of empirical research findings particularly with regard to the university phase of teacher education. Beside the efficacy of pre-service teacher education in general, the structure of physics teachers’ professional action competence and the interaction of its components are of specific interest (Abell, 2007). Our study focuses on this by developing a model of professional action competence of pre-service physics teachers referring to Shulman’s (1986) model of professional knowledge widened by dint of beliefs and personality factors. In a second step the model is applied to generate an instrument in order to measure different aspects of competence according to theoretical principles. In this context, a possible procedure of how to operationalize physics teachers’ PCK as a part of their professional competence is shown in this paper. Furthermore, first results concerning the role of PCK within physics student teachers’ professional knowledge are reported.

Introduction

Large scale assessments like PISA (e.g. Prenzel et al., 2006) have pointed out lots of deficiencies in the German educational system; hence teacher education has come under close scrutiny. As a consequence processes of restructuring teacher education programs have been initiated in the last years, however, without definitely knowing how teacher education takes effect. There is a lack of empirical research findings, particularly with regard to pre-service science teacher education. Up to now it is unclear to which extent needed professional skills and competences like pedagogical content knowledge (PCK, cf. Shulman, 1986) are acquired and what their development is like in the university phase of teacher training. E.g. a common deficiency of research in this area is that subject related knowledge is only measured by the number of college science courses taken (Abell, 2007). In addition to this, the structure of physics teachers’ professional competence and the interaction of components like e.g. content knowledge or pedagogical content knowledge is an open research problem.

Our study addresses these problems by developing a model of professional action competence of pre-service physics teachers in order to identify the necessary competencies to accomplish their prospective vocational demands. Based on this theoretical model, a quantitative instrument is generated in order to measure different aspects of competence according to theoretical principles. After several steps of piloting and validating, this instrument is used in several universities to get findings concerning the extent and the interplay of identified components of student teachers’ professional action competence in physics and its development within the university phase of teacher training. This paper concentrates on aspects regarding physics student teachers’ PCK.
Rationale

Summarizing the findings in the domain of investigating the efficacy of teacher training, Baumert & Kunter (2006) developed a heuristic model of professional action competence. This model is used in the fields of mathematics within the “COACTIV” study (Baumert et al., in press) and the “Teacher Education and Development Study – Mathematics” (TEDS-M, Tatto et al., 2008), in which professional action competence of mathematics teachers respectively of mathematics student teachers is investigated. Comparable studies regarding teacher education in physics are up to now not available.

At the core, the model draws on Weinert’s (2001) conceptual clarification of the concept of competence to characterize the structure and the development of teachers’ professional action competence. Thus, competences refer to necessary prerequisites available to an individual for successfully meeting complex demands in a specific domain. According to Weinert (2001), the structure of professional action competence arises from the structure of the corresponding vocational demands.

Against this background, one aspect of professional action competence reported in the literature is professional knowledge. According to a classification established by Shulman (1986) and widened by Bromme (1997), three aspects of teachers’ professional knowledge can be identified (see fig. 1): content knowledge (CK), pedagogical content knowledge (PCK; consisting of curricular knowledge, knowledge of student misconceptions and difficulties, knowledge of subject-specific instructional strategies and subject-specific pedagogical knowledge) and lastly pedagogic-psychological knowledge (PK). With regard to efficient and adequate acting in a specific situation when teaching, it is important to relate and integrate these different components (Brophy, 1991). Furthermore, it has to be considered that professional action competence, beside theoretical skills and knowledge, also comprises practical skills and knowledge up to the development of patterns of acting (Fenstermacher, 1994).

![Figure 1. Model of competence structure.](image)

Beside cognitive components of teachers’ professional action competence, beliefs (e.g. subjective theories of teaching and learning, self-efficacy beliefs) constitute further influencing factors related to nearly every aspect of the teaching-process (Jones & Carter, 2007). In addition, personality factors like professional values, intrinsic motivation and achievement motives represent further facets of professional action competence. While our study researches a wide construct (fig. 1), this paper focuses von PCK as a part of physics teachers’ professional knowledge.
However, in order to investigate the structure and development of physics student teachers’ professional knowledge and professional action competence within or at the end of the university phase of teacher education, this model has to be modified. Student teachers are, obviously, not able to act like experienced teachers. So, in a structured teacher education (in Germany a 3-4 year phase of academic education at university is followed by a 2 year phase of induction teaching at school) the level of competence at the end of the university phase has to be determined and to be taken into account when investigating the efficacy of pre-service teacher education. In Germany, for example, student teachers should be able to analyze lessons and to suggest how to act adequately; in doing so their decision should be based on (science) educational theories and research findings (Lersch, 2006).

Methods

With regard to the objectives of our study, the first step was to generate a model of competence. Because of the limited time while surveying, we focused on the content domain mechanics and on the role of experiments concerning physics instruction. The first focus is well-founded due to the fact that content knowledge in mechanics is a good predictor for content knowledge in other domains of physics (Friese & Lind, 2004). The second focus reflects the importance of experiments in physics instruction (Lunetta, Hofstein & Clough 2007). It has been observed that in Germany about 60 % of the time of a normal physics lesson is related to experimenting (Duit et al., 2004). So there are findings that the chosen focuses can be conceived as representative for the demands of physics instruction.

In order to generate the model of competence, the above-mentioned general structure of competence was concretized based on common conceptualizations (e.g. Magnusson et al. 1999; Shulman 1986) by using normative models (e.g. conceptual change, cf. Posner et al., 1982; inquiry teaching, educational reconstruction, cf. Kattmann et al., 1996), empirical research findings and observations of best instructional practice from video studies (e.g. Duit et al., 2004; Seidel et al., 2006). Furthermore, we used interviews with experts (experienced teachers, teacher trainers and academic teacher educators) when completing the model of competence. Grounded on this, we operationalized PCK by generating a heuristic framework to make sure that all relevant aspects are represented by test items within the developed instrument. In doing so, the following relevant facets were identified:

A) Knowledge about general aspects of learning physics,
B) Knowledge about a proper use of experiments,
C) Arrangements of learning processes,
D) Assessment and reflection of learning processes and
E) Adequate reaction in critical situations.

Based on the modified competence model and the above mentioned heuristic framework a questionnaire instrument was devised which encompasses the three aspects of professional knowledge, beliefs, attitudes and personality factors. All in all, 90 min are needed to work on the test, so that it can be used within courses at university. Within this, our instrument to assess PCK is a standardized written questionnaire with a working time of 25 min. On the one hand, the questionnaire measures declarative PCK by open-ended and also by multiple choice items because the latter are easy to assess. On the other hand, it measures procedural PCK by using self-developed situational judgment tests we call teaching vignettes.

Teaching-vignettes represent critical situations in the context of physics-lessons. According to Oser (2006) this type of task is suitable to measure teacher’s ability to integrate and to apply different domains of competence. It is assumed that, when the surveyed physics student teachers have to analyze these situations, have to detect students’ misconceptions, have to assess students’ achievement and have to make a suggestion of how to continue in an adequate way, conclusion about their professional action competence can be drawn. In doing so, we don’t use a video based but a paper-pencil-test because we want to survey a wide-ranging conceptualization of competence in
a bigger sample within a specific time limit by reasonable effort. Furthermore, we focus on competences concerning the academic part of teacher education, so it’s not so bad that we only assess what can be learned at university.

The whole instrument was piloted a first time in a group of N = 45 physics student teachers attending one university and different semesters in order to get a high variance. Based on item-analyses, the instrument was revised to get an empirically meaningful basis for the further development of the instrument. In a second step, the operationalization and specific open-ended situational judgment tests of the questionnaire (teaching vignettes, see above) were validated by interviewing experts like experienced teachers, teacher trainers and academic teacher educators.

In doing so, the experts were asked about demands and critical situations when teaching physics. The results of these interview parts were used to get further information to specify our model of professional action competence of pre-service physics teachers. Furthermore, the experts had to assess the critical situations of the teaching-vignettes with regard to relevance in respect of content and representativeness; afterwards they also had to specify and categorize the tasks and problems. Finally, they had to explain how they would react in such situations in order to get adequate options for action within the sample solution. This was necessary, because not all test items (especially reactions to the teaching vignettes) could easily be judged as right or wrong regarding science educational theories and findings.

The once more adapted instrument was piloted a second time in a group of 55 physics student teachers, now from four different universities, to make sure that the instrument can be used not only in the teacher education program of a specific university. After all, the main study (Jul. 2008 – Jan. 2009) was conducted with 301 physics student teachers, attending 11 universities.

**Results**

Psychometric properties

After those several steps of piloting the questionnaire, a well-working instrument was available in the main study. The test’s component related to teachers’ PCK consisting of 39 items has a reliability of $\alpha = 0.74$. Furthermore, the shapes of the distributions concerning the test-persons’ total score as well as the items’ difficulties (fig. 2) imply that the instrument is neither too difficult nor too easy and that there is enough variance with regard to statistical analyses.

In order to ensure the objectivity of the instrument, we created coding manuals with solutions based on the literature as well as on statements of experts (see above). According to this, we found a good interrater-reliability randomly measured by intra-class-correlation ($ICC = .91; F(25,25) = 20.94; p < .001$).

![Figure 2. Histograms referring to the relative total score in PCK (left) and the items’ difficulties (right).](image)
We also tried to ensure the content validity of our instrument by interviewing those experts. Furthermore, we carried out a criterion-related validation by comparing groups with different expertise levels like student teachers, teacher trainers and academic teacher educators. We found increasing test scores for groups with greater expertise (ANOVA F(2, 72) = 7.35, p = .001). Finally, we tried to guarantee the construct validity by conducting a discriminant validation (the test was given to some physicists, too) as well as by a combined data-collection with an independently developed instrument. We found a correlation between the two instruments measuring PCK that was higher than the correlation of our PCK-part with our CK or PK-part (fig. 3). Furthermore, the correlations indicate that PCK has a kind of middle-position between CK and PK.

Structure of physics student teachers’ professional knowledge

Looking at the correlations within physics teachers’ professional knowledge (fig. 3), the question arises whether PCK and CK are independently of each other. Respectively, how far is CK a necessary prerequisite of PCK? There are some hints in the literature that CK might be a good predictor of PCK (Terhart, 2002). To get evidence concerning these questions, a scatter plot (fig. 4) shows that there are test persons with high scores in CK but low scores in PCK, but the other way cannot be observed.

This might be a sign that CK is a necessary prerequisite of PCK. It’s not possible to be good at PCK according to our conceptualization without CK. At the same time, the graphic shows that there are test persons with very low relative total scores in CK (< 15%), but virtually no persons with extremely low relative total scores regarding PCK. Obviously, PCK can be reconstructed to a certain extent with experiences made besides the teacher education program (e.g. as a pupil in school).

Figure 3. Correlations within professional knowledge.
To describe the demands of teaching, we have to research the structure of competence more in general: What kind of professional competence or knowledge is necessary to act within the teaching process? What is necessary to cope with critical situations in the context of physics-lessons that are represented by the teaching vignettes in our test? And what's the relationship between different parts of professional knowledge? Up to now it's unclear, whether PCK fulfills a mediating function within the different domains of professional knowledge or whether all domains have an equal, independent influence.

In order to investigate the structure of physics student teachers’ professional action competence, we use structural equation models (SEM). In doing so, we analyzed how the ability to cope with critical situations – measured by the vignettes – on the one hand is connected with those three parts of professional knowledge (CK, PCK and PK) on the other hand. Tested models e.g. relating to solely direct loadings of CK, PCK and PK on the vignettes or pure mediator-models in terms of PCK do not fit to our data. Distinguishing between analysis-related and action-related parts of the ability to cope with critical teaching situations (empirically verified by confirmative factor analysis) improves the model-fit. Finally, a combined mediator-model whose structural part is shown in figure 5 exhibits the best model fit as the characteristic values show ($\chi^2 = 3.27; \text{df} = 1; \ p = .071; \ RMSEA = .088; \ CFI = .991; \ SRMR = .021$).

More in detail, the diagram shows that CK has a strong direct impact when handling critical situations in physics instruction, especially when analyzing the teaching-process ($r = 0.29^{***}$). Furthermore CK is mediated by PCK to a great extent ($r = 0.28^{***}$). On the other hand, there is only a low direct impact of PK on the ability to cope with critical situations, especially regarding analyses of physics instructions ($r = 0.07$). However, PK has a great indirect effect as it is mediated considerably by PCK. So, PCK has a very important mediating function integrating different aspects of professional knowledge with regard to the teaching-process. Hence, CK and PK seem to be prerequisites of PCK which implies that student teachers need a basis of CK and PK before learning PCK. Furthermore, our data implies that PCK seem to be the most relevant domain of professional knowledge when acting in critical situations in physics instruction ($r = 0.30^{***}$).
Conclusions and Implications

In view of the current discussion with regard to a reorganization of the first phase of teacher education, our study provides a statistically well working instrument with good psychometric properties to measure different aspects of physics student teachers’ professional action competence based on a theoretical model of competence. In the process of upcoming pre-service teacher education reforms, we are able to provide empirical evidence as we are able to identify shortcomings and therewith potential improvements. Additionally, our instrument can be used to evaluate teacher education programs of particular universities, since, obviously, there are great differences between different universities.

Concerning the structure of physics teachers’ professional knowledge, our findings suggest that PCK has an important mediating function with regard to the teaching process, whereas CK and PK can be seen as prerequisites of PCK to a certain degree. These findings should be considered when restructuring teacher education programs. In particular, teacher education programs have to supply student teachers with a wide range of opportunities to learn PCK as there are findings that teachers’ PCK has a great influence on their ability to act within the teaching process.

Beyond, further in-depth analyses will allow more detailed findings concerning the interplay of the identified components of professional action competence along with an identification of specific pattern of beliefs and personality factors. Finally, the instrument will be validated with regard to high-quality instruction, however, in a subsequent project.

Figure 5. Structural equation model with regard to the relation of professional knowledge and the ability to cope with critical teaching situations (* p < 0.05; *** p < 0.001).
MEASURING PHYSICS TEACHERS’ DECLARATIVE AND PROCEDURAL PCK

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Abstract

The purpose of this study is to investigate physics teachers’ Pedagogical Content Knowledge (PCK) and its influence on cognitive activation and students’ achievement. Referring to a basic definition by Lee S. Shulman PCK embraces the idea that teachers have a special notion of content knowledge and pedagogy which they draw on in teaching contents. In this regard, PCK describes the teacher’s understanding of enhancing students’ learning and understanding of specific subject matters. Recent research discovers a lack of instruments to investigate PCK especially in physics. Reliable and valid tests to measure this facet of teachers’ professional knowledge are yet to be constructed. In scope of an international comparative study between Finland, Germany and Switzerland physics teachers’ PCK was modelled and a reliable and valid instrument to measure it was developed. This important part of teachers’ professional knowledge is gathered with a written test with open-ended items. The construction of this measuring instrument for physics teachers’ PCK is described: the structure of the test, the categories and a description of the items as well as the results of 92 physics teachers from all three countries are shown. The test achieves satisfying psychometric values.

Introduction

Teachers’ professional knowledge, especially their Pedagogical Content Knowledge (PCK) has been shown to be an important factor influencing quality of instruction. Regarding recent research on PCK Shulman’s definition for teachers’ PCK provides a basis for research in this field. Referring to Shulman (1986, 1987) teachers’ PCK contains the teacher’s estimation of enhancing students’ learning and understanding of specific contents. PCK covers i.e. the modality of how a teacher prepares contents for students and how he formulates suitable tasks within his prearrangement and during the lessons. Besides knowledge of students’ misconception and an estimation of difficulty of contents knowledge of curriculum is named as an important part of teachers’ PCK (Wilson, Shulman & Richert, 1987). The investigation of teachers’ PCK is a fruitful field for research on teachers’ professional knowledge and especially on quality of instruction.

Rationale

Recent research on teachers’ professional knowledge identifies teachers PCK as an important criterion for instructional quality (Hill, Rowan & Ball, 2005; Jones & Moreland, 2004). In this context the US-American LMT-study (Hill et al., 2005) and the German COACTIV-study (Baumert et al., 2004; Krauss et al., 2008) showed that PCK is a good predictor for students’ achievement and instructional quality in mathematics. Jones and Moreland
who investigated PCK in the context of technology education found that enhanced PCK is positively related to students’ learning, interest and motivation. The teacher constitutes an important part of instruction. He chooses a specific content, and designs and performs his lessons and is thereby responsible for students’ learning. The structure and selection of tasks and material are necessary criteria for cognitive activating mathematics instruction and for students’ achievement (Baumert et al., 2004) as well as adequate reactions to the students’ needs during a lesson.

Referring to Shulman’s basic definition for teachers’ PCK the German COACTIV-study (Baumert et al., 2004) splits PCK into two facets to investigate mathematics teachers’ PCK: declarative and procedural knowledge. The declarative part covers theoretical knowledge about misconceptions, the curriculum and difficulties of contents. The procedural part encloses knowledge about activities and how to react during a lesson. This includes i.e. if a teacher is able to react directly on students’ questions and mistakes in a suitable way. Baumert’s (2004) definition covers the aspects shown in Figure 1.

Figure 1. Facets of declarative and procedural PCK referring to Baumert et al. (2004).

Within this definition Baumert et al. (2004) avail themselves of an approach which is also used by Tamir (1988) in his discrimination between ‘Knowing that’ and ‘Knowing how’. Furthermore Park and Oliver (2007) act on this suggestion by distinguishing between ‘Knowledge on action’ and ‘Knowledge in action’ in addition to take into account that there is a difference between PCK and knowledge that is necessary and used for reacting adequately during teaching. The research project which is commented on in this article uses the differentiation between declarative and procedural knowledge to investigate physics teachers’ PCK as well as the implementation of teachers’ procedural knowledge during instruction. As there is a lack of instruments to measure PCK especially in physics this research project first aims for the development of a reliable and valid instrument. In addition we investigate teachers’ declarative PCK in physics and its effect on physics lessons, especially on students’ cognitive activation and thereby the influence on students’ achievement. For those two parts of knowledge two different ways of measurement are needed: the declarative as well as some of the procedural facets are covered with a written test and the implementation of procedural knowledge is gathered with high-inferent video analysis. Both instruments are described below with a main focus on the written test.

Methods

This project is part of a study called “Quality of Instruction in Physics” (QuIP) comparing physics instruction in Finland, Germany and Switzerland. The sample consists of 107 classes from all three countries. Within a pre-post design students performance and motivation are assessed. Between pre and post test an intervention of a unit on electricity is performed from which two lessons on electrical energy are videotaped. Additionally, students’ and teachers’ background, students’ interest, teachers’ enthusiasm and students’ cognitive abilities and achievement are surveyed and tested. The major aim is to explain differences in students’ achievement by country specific characteristics of all the controlled variables. For the investigation of teachers’ declarative and procedural PCK two different instruments are developed: a written test and a coding system.
Measurement of declarative PCK

The paper-pencil-test for PCK contains 16 tasks consisting of 26 items. All tasks are structured by starting with a short introduction followed by several items. The introduction describes a typical fictional situation of a lesson or shows a picture or an experiment the teacher is asked to judge. The items belong to one of eight categories named in figure 2: (A) Knowledge about students’ misconceptions, (B) knowledge about the relevant curriculum and (C) an estimation of difficulties related to physics content.

![Figure 2. Categories of the PCK-test.](image)

Each item poses a question related to the item’s category. An item of group A will for example ask the teachers to identify all possible misconceptions a student may use in a given instructional situation. All items are open-ended to capture the amount of correct answers a teacher can possibly come up with. For judging the correctness of an answer, a prototypical example solution was created by reviewing comprehensive literature and by expert ratings. The experts were for example asked to name suitable and inappropriate aspects of a situation explained in the task. All aspects were listed and used to analyze the teachers’ answers. If a teacher names an aspect of the list he gets one point. As it did not happen that teachers used aspects which are not listed we assume the list to be comprehensive. The psychometric properties of the PCK-test will be described below.

Measurement of procedural PCK

The videos recorded in the QuIP-study will be analyzed with a coding system to investigate the implementation of procedural PCK. According to Baumert (2004) the coding system consists of three parts: (E) ‘Reaction on students’ answers and mistakes’, (F) ‘Selection of tasks during the lesson’ and (G) ‘Assignment of tasks during the lesson’. The coding system to gather teachers’ implementation of PCK during the lessons is based on existing coding systems by Trendel et al. (2007) for recording the fit of the learning process applied by the teacher, Lau et al. (2006) to estimate the fit between a teacher’s demands and the students’ answers and on the German IPN-videostudy (Kobarg & Seidel, 2006) which focuses on teachers’ statements and especially the feedback a teacher gives to his students.

Results

This research project reaches for a reliable and valid instrument to measure PCK in physics. As the associated symposium focuses on different approaches to investigate PCK the results are restricted on the psychometric properties. The main focus is on the written test because video analysis is ongoing at the moment and is not yet completed.

For the final analysis the test was performed with 92 teachers from Finland, Germany and Switzerland. Four items had to be excluded due to two reasons. One item belonging to ‘Conceptual Change’ has lost its meaning by
translating it into Finnish. Three items belonging to the category ‘Assignment of contents to grades’ were excluded because it was impossible to develop a sample solution for those items in Switzerland because in Switzerland each canton has its own curriculum and they are not compulsory for schools. Due to this it is not possible to judge if a Swiss teacher gave a correct answer. So, the following calculations were done with only 22 items.

Psychometric properties

**Objectivity**

To guarantee the objectivity we doublecoded 10% of the testbooklets (N=9). For this doublecoding we used German and Swiss tests coded by one German rater and another bilingual one (Finnish/German). Both raters achieved a satisfying interrater-reliability: Cohen’s Kappa reaches the value 0.67. After reaching a suitable value for the interrater-agreement the bilingual rater continued analyzing the Finnish testbooklets.

**Reliability**

The value for Cronbach’s alpha of the developed test for PCK confirms that the test is reliable. All items measuring PCK generate one scale. Over all items of the test Cronbach’s alpha is 0.78, so the test can be seen as internally consistent. In addition, a factor analysis could not find the three categories ‘Knowledge of misconceptions’, ‘Knowledge of Curriculum’ and ‘Estimation of difficulties’ as different factors. This leads to the conclusion that the content areas of the test are facets of teachers PCK but they are not disjunct. Those three facets span teachers PCK.

**Validity**

The validity was checked by external validation with another paper and pencil test measuring physics teachers PCK on mechanics (Riese et al., 2009). Both tests were handed in to 77 pre-service teachers for upper-secondary schools. A significant correlation between both test-scores was found. Spearman’s rho reaches a value of 0.64*** (Borowski et al., 2009).

Within the QuIP-study teachers’ content knowledge (CK) was also investigated with a short test concluding multiple choice items. We achieved a significant mid-size correlation between teachers’ PCK-score and the score of those CK items which deal with electricity. Spearman’s Rho is 0.174* for this correlation. Both tests measure different constructs, but we can also support the results of recent researchers who postulated CK as a good predictor for PCK in mathematics or technology education (Hill et al., 2005; Jones & Moreland, 2004).

It is also planned to hand in the test to physicists and to teachers who teach another subject than physics for discriminant validation. The aim is to show that those participants do not reach a higher value in the PCK-test than physics teachers do.

**Conclusions and Implications**

As data analysis is still ongoing we are not yet able to draw any comprehensive conclusions regarding differences between the teachers of the three participating countries. The development of the written test to gather PCK leads to a reliable and valid instrument. So, it measures PCK according to the described model and can be used for the international comparison of Finnish, German and Swiss teachers.

An additional benefit of this approach to measure teachers’ PCK is the video analysis. With this approach it is possible to analyze teachers’ use of theoretical knowledge in their lessons and how they implement their skills during their lessons. This study expects to add more information about teachers’ PCK in physics and its feasible impact on students’ achievement to explain differences between students from different countries regarding their competence in physics.
References


“Travel teaches how to see”
Science teaching as a navigation across borders

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Abstract

“Travel teaches how to see”: the proverb suggests that we cannot cherish a journey unless we are open to learning. Conversely, it might be true that we cannot learn unless we are ready to travel. Starting in a shared belief that science education essentially is about travelling across borders, the authors develop their ideas of which borders there are and how they can be transcended in both formal and informal learning environments. Analysing the subcultures of learner and learning-object indicates the border but lacks the means for crossing. Easing the transition by pulling learners into the teaching object in an immersion exhibit is one of the proposed ways in this symposium. Another one is to discuss an intrinsically interdisciplinary subject which eases learners’ border crossing through disregard of traditional discipline borders. Concerning this, nano-science and -technology will be discussed from an exhibition-designer’s as well as a school teacher’s point of view, who wants to facilitate conceptual change. The fourth paper in this symposium suggests that upholding border-crossing in science learning requires teachers who are confident in this, and therefore argues for the development of special teaching materials. The symposium shows how different approaches to border-crossing might complement each other in science education.

Introduction

When thinking about Teaching and Learning Science one quickly encounters that something makes it especially hard to help students (or learners in general) to understand science and scientific content. This something might be responsible for the limited popularity of science disciplines in school or even later on in life. Determining what this something is and how science educators could be prepared to address it, and in doing so could eventually overcome it, might be of the essence for future science education and its success. Research on science education has identified many factors already that affect and influence the success of science teaching but it has sometimes failed to look beyond the symptoms of ‘mis-teaching’, thus failing to identify its causes. This collection of papers tries to illuminate how a fundamental understanding of science-teaching as negotiating borders between subcultures might be exploited in science education research, and how science education itself may ultimately profit from it.
Rationale

Border-Crossing in Science Education

A worthwhile notion to look into, when considering science education, has been introduced by Glenn Aikenhead (1996). He suggested that science education is basically about border-crossing between different subcultures. By ‘culture’ he understands (relying on Geertz’s, 1973 definition) “an ordered system of meanings and symbols, in terms of which social interaction takes place” (ibid., p. 5). Cultures can be composed of a variety of subcultures that principally share a system but apply slight differentiations in some nuances. At any given time, there are several cultures (or subcultures) in coexistence that are defined by shared sets of norms, values, beliefs, expectations, and conventional actions (cf. Phelan et al., 1991). When two or more (sub-)cultures come into contact, problems might arise from the differences between their shared sets of symbols, norms, etc. Aikenhead suggests that this principally is the case when looking at Science Education.

In school, according to his reasoning, students coming from their own cultural background of friends (peers) and family are confronted with the subculture of school science. These two subcultures differ immensely in terms of, e.g., perception (e.g. scientists invent ways of observing, describing and interpreting natural phenomena even where they are limited by their biological senses), vocabulary (e.g. ‘energy’ represents different, at times even contradictory concepts in the subcultures) and reasoning (e.g. ethical questions might have different status depending on whether a decision is made in a family or for a society) and, thus there are borders between the cultures that hinder (or even prevent) smooth translation between these subcultures. Successful science education helps students to navigate across the chasms between the cultures, i.e. helps them to negotiate the border-crossing. Thus, successful science education needs to analyze the border-regions more closely in order to find out where exactly students are located in relation to the subculture they need to enter (school-science) and which aspects between the subcultures seem to be most problematic to transcend.

Principal Types of Borders in Science Education

Knowing that there are borders between the cultures and what exactly constitutes them does advance sound and successful science education, but falls short of one distinction. We suggest that there are two substantially different types of border that cannot be negotiated with the same means and, therefore, need to be understood as being different from the very beginning. As science culture differentiates itself from everyday culture in at least two principal aspects, these form borders of their own kinds: (1) Science can be understood to be a means to organize and structure a certain kind of knowledge pertaining to natural phenomena; (2) it can be understood as a means to observe and explain these phenomena. Therefore, two principal types of limitations border science culture from everyday culture. One is defined by subject-boundaries and systematizations that aim at organizing content knowledge. It has been argued that crossing the borders between disciplines is central to scientific literacy and the demands a modern world poses on learners, so science education needs to find ways to address these borders adequately (cf. Bartosch & Elster, 1998; Lang, Drake, & Olson, 2006). The second kind of border is constituted by the scope of our sensorimotor abilities and a notion of other-worldliness (cf. Belaën, 2003, Montpetit, 1996, Fladt & Buck, 1996); scientists do not stop where biological vision or hearing fail them but they rely on models and instrumentations to overcome their senses’ limitations.

Negotiating these two types of borders – ‘discipline borders’ and ‘perception borders’ – poses different challenges to the science educator. While the first challenge primarily reaches out to enhance students’ systems of content-structures and to familiarize them with different branches of science and the connections between them, the second asks them to deliberately not trust their senses and to stretch their imagination beyond these. In other words: while one pointedly applies to matters of content knowledge, the other rather embraces the learners’ beliefs. So, suggesting that science education always involves border-crossings plus reflecting on the different kinds of borders
might provide “science educators with a new vantage point from which to analyze familiar problems.” (Aikenhead, 1996, p. 1)

‘Travelling’ as a Metaphor and the Educational Compass

Thus, understanding science education to be characterized by the continuing negotiations between cultural borders, one can compare learning and teaching of science to a quest into unknown territories; i.e. the learners undertake some kind of expedition into the unfamiliar subculture. Just as the traveler in an expedition needs to cross different borders (physical and psychological ones) when going to another country, the learner of science needs to negotiate the different borders as introduced above.

Yet, the metaphor suits another twist, too. When going onto a trip to an unknown region, the traveler will rely heavily on guidance of some kind and will have to clarify beforehand which path he is going to choose. This will predetermine what he will be able to see on his journey (e.g. leaving Kathmandu on a southbound track will rob you of the opportunity to see Mount Everest from nearby). The guidance the traveler might seek will most probably come in the form of a guide or an expert in the field. And just as the guide through rough landscapes will rely on a device to facilitate orientation, science education researchers (as the experts in science education) should employ a comparable kind of compass in their work which will codetermine what can actually be found. Learning from the traveler, who is aware of the limitations and benefits of the geographical compass, science education researchers should be prepared to take the limitations of their navigating instrument into consideration, too.

So, likening science education to a journey of unknown territories asks the researcher of science learning to make use of an educational compass as to ensure the choice of an adequate route. We suggest that the four cardinal points of this compass, towards which the researcher can orientate themselves, are as follows (cf. Fig. 1): Learning Goals (i.e. the metaphorical Destination); Instructor (Guide), Learner (Traveler), and Teaching-/Learning-Media (Route). Each of these four points is relevant in teaching- and learning-settings but usually the researcher has to decide on one of these they would like to focus on. In the decision on a focus potential observations and findings are already inherently bound. So, the researcher is well-advised to clarify in advance which course to set in order to find what they want.

![Figure 1. The educational compass](image)

The Papers

Originally, the papers in this symposium took an epigraph related to travelling. As the metaphor introduced above appears to us to be a powerful one, we chose not to overindulge on it and present the short abstracts leading in to the individual papers under their science-education-research-headings. Indicated for each of the papers, the reader will find the direction of the compass-needle, though, and a short overview of the respective paper’s content.
Designing Museum Exhibits as Border-Crossing Environments (Marianne Foss Mortensen)

Marianne Foss Mortensen is ‘headed east’ because she theorises on the optimal route to a given destination. She suggests that understanding science-teaching as a border-crossing enterprise is fundamental to the design of immersion exhibits. In this special class of museum exhibits, visitors are encouraged to enter into other worlds and to perceive them from within. Applying the compass terminology, this represents a quintessential case of addressing those borders posed by perception. Suggestions for optimisation of such exhibits are illustrated introducing an exhibit on the life of a cave-beetle.

Interdisciplinary Aspects of Nanoscience and Nanotechnology for Informal Education (Antti Laherto)

Antti Laherto discusses exhibition development as well. His paper, in contrast to the preceding one, deals with ‘discipline border-crossing’ as in terms introduced above. While identifying possible routes to transcend discipline-borders in the context of nanoscience and nanotechnology, the direction in the educational compass is south-east. Indeed, the focus of the paper lies on understanding the interdisciplinary nature of nanoscience and -technology – in our metaphor the ‘destination of the journey’ – as well as on the means to convey these ideas in informal settings, i.e. the ‘route’.

Effecting Conceptual Change through Teaching Nanotechnology and Perception (Martina Bruckmann)

Working on nanoscience, too, Martina Bruckmann has designed a special teaching unit. “The size is the kick” means to ease conceptual change for advanced students in German secondary schools. It simultaneously treads both border-types sketched out above but centres on guiding students across the border between the macroscopic and submicroscopic worlds. Assuming that this route due east will confirm the feasibility of that trail, she presents findings from the unit’s genesis as well as from a study on its effectiveness.

Supporting Teachers to Transcend Disciplinary Borders (Markus Emden)

As secondary schools are most likely the loci in which people accomplish their first significant border-crossings into science, Markus Emden focuses on the design and evaluation of teaching materials for science. Because German teachers are typically trained in no more than two science-subjects, these materials for integrated science courses point west: Teachers themselves need to feel comfortable in transcending discipline borders if they want to assist students in this crossing. An evaluation study is introduced that investigates in how far supporting teachers in their own border-crossing bears positive effects on students’ achievements.

Summary

Practical development and academic research on science education are highly diverse fields owing to the variety of starting points, interests and approaches (cf. Duit, 2007). The authors in this symposium discuss this range by comparing science education to travelling into unknown terrain. They suggest that, though there certainly is orientation in the field of science education, there is not one cardinal path but different approaches that can successfully be taken. Depending on whether an education researcher emphasizes desired learning outcomes rather than studying the students, for example, the paths through the territory of science can be significantly differing ones. Science education is not a jungle, neither is it a well-laid-out trip. In order to succeed, a science educators and researchers alike need to decide on what they want to achieve or find out primarily. From their combined experience, valuable innovations in science education might grow:

- Is a certain domain of science worthwhile for all learners to encounter? – Then analyse the domain at hand and identify its distinctive features. Do away with auxiliary aspects but make sure that those retained are exemplary and represent the field well.
- Does each group of learners require its own customised path to arrive at a certain destination? – Then start by identifying the needs and wants of the group. Only then can it be decided which steps to take in creating learning environments on the topic. The way that seems easiest to the educator might not be the most convenient way for the learners.
Does the success of the journey massively hinge on the qualification of the travel guide? – In this case, one might be well advised to ensure that an educator is fit for the task bestowed on him. If the educator feels unfit in any way, he cannot be expected to perform at his best and thus successful science education is jeopardized.

This symposium demonstrates that – no matter which main course is set – a worthwhile journey through science can come of it. There is not one golden path. Consider: When a stranger asks for directions, you usually take his needs into account and advise a different route according to what you think fitting for the stranger (the fastest lane, the most straightforward directions, the most scenic route, etc.). Shouldn’t we consider a journey through science at least as meticulously?

References


Abstract

The present study introduces the concept of ‘immersion exhibits’ in museums which differ from the classical dioramas of old in so far as they try to pull the visitor into the exhibit and make them part of it. Depending on the degree to which visitors actually participate in the exhibit one can differentiate between three types of visitors: (1) Resonance visitors, (2) Distance visitors, and (3) Rejection visitors. This paper discusses each of these types briefly, as they represent different challenges to the designers of an immersion exhibit, i.e. how the visitor needs to be addressed in order to ‘lose’ themselves in the exhibit. In light of the notion of ‘border-crossing’ this paper introduces potential ‘culture brokers’ (Aikenhead, 2001) that might be employed in an immersion exhibit in order to immerse members of each of the discussed visitor types deeper into the exhibit. Implications that arise from the visitor types’ differing readiness to cross borders are addressed and can serve to support future developments of immersion exhibits.

Introduction

Science museum exhibits are recognised as important learning environments, yet there is little research available to exhibition creators on how to achieve visitor learning outcomes. Consequently, exhibition design remains largely based on the tacit professional knowledge of museum staff rather than theoretical or empirical evidence. Here, a special class of science museum exhibits, immersion exhibits, are analysed as border-crossing environments to synthesise theoretical suggestions for the design or optimisation of such exhibits.

The epistemological development of science museum exhibits from the historical diorama to present-day immersion exhibits and the changing role of the visitor in this process were discussed by Montpetit (1996). From being a spectator to the traditional glass-encased dioramas and thus “at a distance of representation”, in an immersion exhibit the visitor is plunged into the heart of the subject matter and is no longer a spectator, but a participant (Montpetit, 1996). It follows that extent to which the visitor apprehends the exhibit’s scientific meaning and message depends on the readiness with which they accept this world and the role assigned to them; a process which may be described using the notion of border-crossing. In this process, the visitor makes a transition from the visitor subculture to the immersion exhibit subculture. The immersion exhibit subculture is thus understood to be a system of meaning and symbols (cf. Aikenhead, 1996) created by the exhibition engineers for the purpose of creating an illusion of a time and place for the museum visitor. Consequently, the problem addressed is: What are the exhibit design criteria for border-crossing, i.e. the successful transition of visitors into the subculture of the immersion exhibit, in a science museum setting?
Visitor reactions to immersion exhibits

Common visitor reactions to immersion exhibits range from resonance, where visitors willingly surrender themselves to the immersion premise, to distance, where the visitor considers the museographic form to be disproportionate to the subject matter, and finally to rejection, where the visitor figuratively and sometimes literally fails to enter the immersion environment (Belaënen, 2003). Applying Aikenhead’s (1996) analysis of science learners’ border crossing characteristics to Belaënen’s visitor typology yields the following description of the three types of visitors: Resonance visitors are visitors who willingly suspend reality and are able to perceive the premise of the immersion exhibit. They take on the role suggested by the immersion exhibit, cross the border into the exhibit microculture, and ‘play along’ with the premise of the exhibit. Distance visitors are visitors who comprehend the immersive premise of the exhibit, but refuse to play along. They seemingly interact with the exhibit as intended (having learned to ‘play the game’) but their life-world-culture is not aligned well enough with the exhibit microculture for them to immerse themselves in the suggested role. Finally, rejection visitors are visitors who do not grasp the premise of the immersion exhibit. These visitors cannot cross the border into the exhibit microculture, and if they chose to engage with the exhibit, non-constructive (i.e. unintended by the exhibit engineers) outcomes are the result.

Designing immersion exhibits to facilitate border-crossing

As qualified in the preceding, the success of an immersion exhibit depends to a large extent on its ability to persuade the visitor to immerse themselves in it and assume their intended role. The exhibit should thus ideally function as what Aikenhead (2001) describes as a culture broker, easing the visitor’s crossing of the cultural border between the visitor’s world and that of the exhibit. Culture brokering entails acknowledging and respecting the perspective of the audience, making explicit the cultural border between the two cultures, and consciously and explicitly moving back and forth between the cultures during the communication event (Aikenhead, 2001). This has different implications for the different types of visitors; here, two design suggestions are made to exemplify the notion of designing for the border-crossing of distance and rejection visitors.

Distance visitors may physically enter the immersive environment, but do not enter it mentally because it is not personally meaningful to them. In order for these visitors to get the intended experience from the immersion experience, their border crossings must accordingly be managed (cf. Aikenhead, 1996).

For distance visitors, knowledge worth learning is likely organised around everyday issues and derived from analysis and reflection. A way of managing their transition into the microculture of the exhibit is therefore to build bridges from their life-world to that of the exhibit subject matter (Aikenhead, 1996), using concepts from these visitors’ daily lives as bridgeheads or founder notions (Küçüközer, 2001, cited in Buty et al., 2004). Such founder notions are commonly held conceptions that do not conflict with what is to be learned, but can serve as the basis on which intended conceptions may be built. Once the initial transition has taken place, i.e. the visitor has accepted the premise of the museographic form, it is then important to for the exhibit design to follow through by forming a framework of meaning sufficiently strong and consistent that the visitor’s imagination can be constructively supported to clarify and deepen the subject matter in terms that are personally meaningful to that visitor (Dufresne-Tassé et al., 2006).

Visitors of the rejection category are the visitors who do not grasp the meaning of the museographic form, lacking the keys of reading to be able to interact with the exhibit (Belaënen, 2003). Unaided, these visitors carry out hazardous border crossings (cf. Aikenhead, 1996) in which they unconsciously navigate around the premise of the immersion exhibit and thus do not apprehend the intended meaning. Rejection visitors, if they enter the immersion exhibit at all, only superficially go through the motions of interacting with the exhibit.
Designing for rejection visitors entails making the features of the immersion microculture recognisable to the visitors on their own terms instead of expecting them to assimilate the exhibit microculture. The first step could be to relocate the visitors’ initial attention from the exhibit content to the exhibit form, i.e. emphasising the experiential aspect of the exhibit (Belaën, 2005). The subsequent engagement with the exhibit should then take the form of a guided tour where the visitor is assisted in moving back and forth between their own subculture and the exhibit microculture and helped to resolve any conflicts that might arise (Aikenhead, 1996). Each side of the cultural border should be explicitly marked to make it overtly clear which microculture the visitor is in at any given time and when a border crossing is taking place (Aikenhead, 2001).

Conclusions

Viewing immersion exhibits as sites of potential border crossing may shed new light on a poorly understood aspect of informal science education, namely how to optimise the design of such exhibits in terms of their ability to achieve their stated learning objectives.

References


INTERDISCIPLINARY ASPECTS OF NANOSCIENCE AND NANOTECHNOLOGY FOR INFORMAL EDUCATION

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Abstract

The theoretical study presented here contributes to one of the symposium themes, ‘discipline border-crossing’, by scrutinizing the interdisciplinary nature of the fields of nanoscience and nanotechnology (NST), and by considering ways of representing those features in an informal learning environment. The paper reports a part of a research project that employs the Model of Educational Reconstruction to develop an exhibition that promotes public understanding of NST. An analysis of the nature of NST points out that the interdisciplinarity of the fields is based on two issues that are shared by the researchers from different disciplinary perspectives: size scale and visions. The paper suggests that these same approaches are useful when constructing content for an interdisciplinary exhibition on NST. On the basis of literature on learning in informal settings as well as research on learning NST-issues, both the advantages and pitfalls of these strategies are discussed.

Introduction

This paper’s perspective on border-crossing

This theoretical paper contributes to the symposium “Travel teaches how to see – Science-teaching as navigation across borders” by focusing on one of the forms of border-crossings in science education, discipline border-crossing, discussed in the symposium preface. From this perspective, the paper scrutinizes the nature of the fields of nanoscience and nanotechnology (NST) as subject matters for an informal learning environment, a public exhibition. These are contexts in which discipline border-crossings are common: on one hand, the emerging fields of NST strive to blur the disciplinary boundaries, and on the other hand, exhibitions as learning environments usually do not entail the traditional boundaries between the disciplines such as in school curricula. Thereby, in terms of the travel metaphor introduced in the preface, both the route (i.e. an exhibition) and the destination of the journey (i.e. an understanding of NST) are very natural and fruitful contexts for discipline border-crossing.

About the concept of interdisciplinarity

In this symposium contribution, disciplinary border-crossing is discussed in reference to interdisciplinarity. In literature that concept has been used in a variety of contexts and for many purposes – thus it has remained a highly ambiguous term (for conceptual overview, see e.g. Klein Thompson, 1990). Interdisciplinary research can arise from several demands, either internal or external; common reasons include a shared interest in an object of study, or some social concerns and demands that do not fit within a single disciplinary frame (Klein Thompson, 1990) – such is the case e.g. in environmental research. The resulting interdisciplinary research comprises both cognitive and social elements; that is because a discipline is a body of knowledge, and on the other hand a social body (such as a people
working in same research institution). There has to be interconnections regarding both of these aspects in order to enable interdisciplinary research (cf. Schummer, 2004). Also, by definition interdisciplinarity means more than *multidisciplinarity* which is much more common in science. Multidisciplinarity signifies the juxtaposition of disciplines, and is essentially additive instead of integrative (Klein Thompson, 1990, 56). Interdisciplinarity, on the contrary, requires stronger ties, overlap and integration of various disciplinary perspectives.

The concept *discipline* has strong educational connotations, and the objective of interdisciplinarity ischarted at least as much in the context of education as in research. It has been a slogan of educational reforms at all the levels: from interdisciplinary universities (in-depth discussion in Klein Thompson, 1990) to integrated school curricula. The advocates for integration of science curriculum argue that interdisciplinary science teaching would support students’ understanding of connections and relevance of concepts to other concepts and broader issues (Czerniak, 2007). This kind of “seeing the Big picture” is considered crucial regarding *scientific literacy* and competences of decision-making in modern societies (Lang, Drake, & Olson, 2006; Roberts, 2007).

In this paper, the symposium theme *discipline border-crossing* is equated with interdisciplinarity in science education. One might yet argue that interdisciplinary science education means more than just crossing borders between disciplines – that it, in addition, includes integrative aspects discussed above. Thereby an interdisciplinary approach wants not only to cross borders but also to bridge the related disciplines, and thus to combine them. The standpoint chosen in this paper considers interdisciplinarity as the kind of border-crossing that happens frequently, back and forth, until the border between the disciplines virtually vanishes.

The broader purpose of the paper is presented in the following chapter, followed by description of the methodology of the study. After that, the argumentation starts with general insights about the interdisciplinary (i.e. *discipline border-crossing*) nature of the fields of NST, and ends up with implications concerning the development of informal learning environments on the topics in question. Strategies for addressing the interdisciplinarity of NST in a public exhibition are discussed.

**Rationale**

As more and more significant societal and economic prospects are attached to the fields of NST, these rapidly developing fields have gained wide public interest and media attention. However, and perhaps paradoxically, results of several surveys and polls have shown that despite the public’s interest in and somewhat positive attitudes towards NST, people’s awareness and knowledge of the fields has remained at a very low level (see e.g. Waldron, Spencer & Batt, 2006). This state of affairs has aroused some concerns, since it is likely that in the near future citizens have to make more and more decisions on NST-related issues – both at the personal level, as consumers, and also at the societal level, regarding the future paths of NST (Baird, Nordmann & Schummer, 2004). Therefore it has been argued that public understanding of these fields should be enhanced, so that people could better participate in the public debate and make decisions on the related issues (Castellini et al., 2007; Healy, 2009). Some level of understanding of these fields has been suggested to be relevant concerning up-to-date *scientific literacy* (Sabelli et al., 2005; Stevens, Sutherland, Schank, & Krajcik, 2007). Besides the societal importance, also the interdisciplinary nature of the fields has played a role in these arguments.

Consequently, methods and strategies of public communication regarding NST have been increasingly discussed in the fields of social sciences, science education and science communication. Informal learning environments such as exhibitions in museums and science centres have been suggested to have a significant potential not only to educate the public about NST but also to contribute to the science-technology-society dialogue (Crone, 2006).
This theoretical paper is a part of a research project in which a public exhibition on NST is developed in order to respond to aforementioned demands. The purpose of the paper is to lay groundwork for planning the exhibition by analyzing the fields of NST, specifically their interdisciplinary elements. Analysing the subject matter – its nature and structure – from an educational viewpoint is an important, yet usually neglected part of exhibition development process in museums and science centres. Furthermore, there is a lack of this kind of content-focused approach also in research on informal learning environments: most of such research is visitor studies aiming at finding general factors that influence visitors' learning in exhibitions (see e.g. Falk & Dierking, 2000; Rennie, 2007). This study, in contrast, concentrates on the scientific content in order to find well-grounded approaches for exhibition design.

Methods

The study employs the Model of Educational Reconstruction (Duit, 2007; Komorek & Duit, 2004) to analyse the fields of NST from an educational viewpoint and to set guidelines for an exhibition on the topics. The model, associated with the design research tradition, combines analytical and empirical educational research with development of practical educational solutions. The basic idea of the model is that the content structure for instruction cannot be taken directly from science content structure, but has to be specially (re)constructed by paying attention also to the educational goals as well as learners’ cognitive and affective perspectives. The Model of Educational Reconstruction consists of three components: 1) analysis of content structure, 2) research on teaching and learning, and 3) design of learning environments (Duit, 2007; Komorek & Duit, 2004). The components are closely interlinked so that results from one component influence the other two components as well.

The part-study reported in this paper focuses on the first component of the Model of Educational Reconstruction, analysis of content structure. The interdisciplinarity of NST is scrutinized on the basis of literature on the nature of the fields, from the critical perspective of science and technology studies (STS). The analysed literature includes philosophical as well as sociological research on NST. Despite the novelty of the fields, an amount of such papers has already been published, and several interesting features regarding the interdisciplinary nature of the fields have been pointed out (see e.g. Baird et al., 2004; Brune et al., 2006).

In addition to the content analysis, the paper also draws on empirical research on learning – i.e. component 2 in the Model of Educational Reconstruction. This literature includes studies on the characteristics of exhibitions as learning environments (e.g. Falk & Dierking, 2000; Rennie, 2007), as well as studies on challenges in learning NST (e.g. Sweeney & Seal, 2008). Findings from those studies are taken into account when suggesting implications for exhibition development in component 3 of the model.

It should be noticed that the paper discusses only a minor part of the educational reconstruction carried out the project, namely the part concerning theoretical analysis of interdisciplinarity in NST. In addition to the literature analysed here, the research project addresses many other aspects as well when setting the guidelines for an exhibition. These aspects include e.g. empirical studies on visitors' perspectives, and content analyses on NST-topics other than interdisciplinarity.
Results

Interdisciplinarity of nanoscience and nanotechnology

In this chapter, some general notions are presented concerning the interdisciplinary elements of nanoscience and nanotechnology. Many fields of NST clearly interlink two or more of the traditional disciplines, mostly physics, chemistry, biology, material science, medicine and engineering. An example of such fields is research on steric effects of cell membranes, where chemists, biologists and physicists have overlapping research interests and approaches that complement each other, and the scientists from different fields also share the same, novel instruments to observe the phenomena.

A lot of expectations rest on this notion of interdisciplinarity of NST, and it has even been proposed as the deciding factor in the progress of NST (Brune et al., 2006). Visions such as the one stated by Stevens et al. (2007) have not been rare: “Because nanoscience represents a convergence of all science disciplines on the nanoscale, nanoscience and nanotechnology promise to have a significantly greater impact on society than previous leaps in scientific knowledge.” It’s a generally accepted idea that the forthcoming scientific and technological breakthroughs will most likely happen in the intersections of the traditional science disciplines. The synergetic effects are considered to give rise to innovative research. Also the reports concerning nanoscale research frequently highlight the necessity of interdisciplinarity (cf. Schummer, 2004). Moreover, it has been argued that interdisciplinarity is central to the alleged novelty of NST; as chemists, physicists, biochemists and cell biologists have been studying the “nanoscale” – the dimension of atoms and molecules – already for centuries, it may be just the interdisciplinary approach that makes NST new (see e.g. Sabelli et al., 2005).

In general, there can be various degrees of interdisciplinarity in scientific research. As Schummer (2004) puts it, interdisciplinarity “can go as far as to either unify two or more disciplines or to create a new 'interdisciplinary' (hybrid) discipline at the interface of the mother disciplines”. Both of these ideas have been suggested with regard to NST. Nanoscale research has been labeled as a melting pot of various disciplines, reflecting the idea of truly interdisciplinary field with no traditional boundaries. Furthermore, NST has been referred to in terms of reductionism of the natural sciences (see Schmidt, 2004); i.e. the scientific ambition is not only to link quantum mechanics, solid-state physics, inorganic chemistry and molecular biology, but to unify them as well – at least partially, in the nanoscale. Related to this idea is the popular view of the hierarchy of disciplines that reflects the size hierarchy of material objects (Schummer, 2004). Some scholars have gone even further, suggesting that NST should be seen as an epistemic revolution or a paradigm change (Brune et al., 2006), and it prepares the way for a greater convergence of sciences, the so-called NBIC-convergence (Hunt & Mehta, 2006; Khushf, 2004).

However, there are also doubts that the aforementioned promises are naive, and based on bad understanding of the nature of science. It has been argued that the so-called interdisciplinarity of NST turns out to be merely multidisciplinarity in closer scrutiny of the actual practices (Schummer, 2004), and NST is just an umbrella term for many fields of research with their own approaches and paradigms. For instance the ideas of atom-by-atom-manipulation and self-assembly are fundamentally so different that genuine interdisciplinarity may be difficult to achieve (Schummer, 2004).

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1 For a comprehensive and fairly up-to-date review of current fields of NST, see Brune et al. (2006).

2 This is common in rhetoric of other fields of science as well; e.g. Thompson Klein (1990, 56-73) points out that most of the alleged “interdisciplinarity” is not actually inter- but multidisciplinarity.
As it is pointed out in the previous chapter, there isn’t an agreement on the degree and nature of interdisciplinarity in NST. In order to analyze that aspect of the fields more closely, we need to have a closer look at what this alleged interdisciplinarity is based on, and how it is promoted in NST research. This chapter distinguishes two approaches for this, and suggests that those approaches may be used also in representing the interdisciplinary nature of NST in an informal learning environment such as an exhibition.

In general, when researchers from different fields engage themselves in interdisciplinary projects, they have to share a common ground other than their disciplinary knowledge (cf. Klein Thompson, 1990, interdisciplinary problem-focused research). This common ground is quite natural when the collaborating scientists are studying the same objects, and/or sharing the same goals e.g. in terms of technological applications or implications. This is exactly the case in nanoscience and nanotechnology. The promises of successful interdisciplinary research in NST are based on two ideas: the size scale of objects and the technological visions about future success.

The size scale of objects is the primary basis for interdisciplinary research on NST. Research is focused on scale rather than some problems that are specific to a certain discipline. Nordmann (2004) even argues that NST is fundamentally place-oriented enterprise that primarily seeks to settle and stake claims at the nanoscale – instead of commonly stated “official” goals such as understanding nature, or production of devices and substances. However, Schummer (2004) questions the sufficiency of shared scale in thoroughly integrating various disciplinary perspectives because of the fundamentally different research approaches.

Despite these reservations, discussing the size scale is a natural starting point for an informal learning environment on NST, reflecting the interdisciplinary nature of the fields. Besides the importance of scale in NST, scale conception is also an important interdisciplinary theme of science education in general, and plays a significant role in scientific literacy as well (see Tretter, 2008). It has also been suggested as one of the “Big Ideas of Nanoscience”, and recommended to be incorporated in school curricula (Sabelli et al., 2005; Stevens et al., 2007). Research has shown that people of all ages have substantial difficulties in understanding the submicroscopic scales (Castellini et al., 2007; Tretter, Jones, Andre, Negishi, & Minogue, 2006). One of the fundamental challenges in public communication of NST is that scientists – and also educators – tend to erroneously assume that lay people are familiar with the basic ideas of the structure of matter and able to comprehend the size scale of nanometres (Castellini et al., 2007). An understanding on nanoscale phenomena can only be built on understanding of atoms as building blocks, including the size of them. Therefore, an informal learning setting such as an exhibition should provide visitors with possibilities to familiarize themselves with the basics of the scale and the structure of matter before going into actual topics of NST. However, the scale and the invisibility of “nano-objects” pose several communicational and museographic challenges regarding exhibition development (see Murriello, Contier, & Knobel, 2009). Visitors’ scale conception may be supported by presenting scales as a continuum with size landmarks, using relative size comparisons instead of absolute sizes, and promoting proportional reasoning (cf. Tretter et al., 2006; Tretter, 2008).

Visions are the other element, a social one (Klein Thompson, 1990), that the interdisciplinarity of NST is based on. The fields are replete with societal visions usually related to general values or human needs such as health, wealth, security or sustainable development. These visions provide some integration of various disciplinary perspectives. They give a common agenda to researchers of different disciplines (Schummer, 2004).
Thus an informal learning environment should address the use of visions in NST in order to represent the nature of the fields in a proper way. Furthermore, visions are not only a central approach in generating interdisciplinary nanoscale research, but also a powerful method in communicating to the public. Visions “provide quick answers to why-questions of a general audience” (Schummer, 2004). The surveys and polls on public’s perspectives on NST have shown that the general interest in the fields is chiefly focused on visions of issues people can relate to, e.g. energy production, pollution or medicine (Macoubrie, 2006; e.g. Waldron et al., 2006). Also ethical issues related to NST (Hunt & Mehta, 2006) are of public interest. Because of the free-choice-learning character of informal learning environments (Rennie, 2007), it is a necessity to address visitors’ needs and interests in an exhibition in order to gain any interaction. However, it has been argued that using scientific visions in public debate to a considerable extent can result in serious problems of communication between science and society (Brune et al., 2006). Balanced and realistic information is needed, and speculative visions should be communicated only deliberately, pointing out also the uncertain and partly unscientific nature of them (Brune et al., 2006).

Conclusions and Implications

Informal learning environments have a significant potential to contribute to public’s understanding of, and engagement in the emerging fields of science and technology. The study presented here is a part of a research project that develops a research-based model for development of exhibition on such fields. The Model of Educational Reconstruction (Duit, 2007; Komorek & Duit, 2004) is used as a basis, drawing on both theoretical content analysis of the subject matter and empirical studies on learning processes. In this paper, issues related to the interdisciplinary nature of NST have been scrutinised in order to find well-grounded strategies for exhibition development and to contribute to the **disciplinary border-crossing** theme of the symposium. The interdisciplinarity of NST is based on shared scale and shared visions. This paper suggests that a public exhibition on NST, promoting public understanding of these fields, should address these features in a deliberate way in order to represent the nature of NST in a proper way.

Interdisciplinarity is a natural starting point for education in NST. Interdisciplinary approach presents challenges to the formal educational system with traditional disciplinary boundaries in both curricula and practices (cf. Sweeney & Seal, 2008). On the contrary, characteristics of informal learning environments (Falk & Dierking, 2000) fit the nature of NST well. Despite several educational challenges, there are reasonable strategies to represent interdisciplinarity of NST in an exhibition.

References


STUDENTS’ AND TEACHERS’ FEEDBACKS ON A PROBLEM-BASED LEARNING (PBL) APPROACH USED FOR INTEGRATING HEALTH EDUCATION IN A HUMAN BIOLOGY MODULE

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Abstract

The aim of this study is to investigate the use of an active learning approach for developing a human biology module integrated with health education and to evaluate its impact on students’ learning experience as well as on their attitudes. Students in four classes of Italian compulsory secondary schools (15-16 y.o.) experienced a problem-based learning approach during a module concerning human biology (circulatory and respiratory systems) as well as a health education issue (effects of smoking). Along six weeks, starting from aspects related to smoking, different inputs were given to students to promote a brainstorming activity and to foster them to research information about the matter. Scientific contents were not given by teachers previous to the discussion. Questionnaires were administered to students to assess their perceptions after the module was completed. Teachers were interviewed to have their feedback. Findings show that the majority of students report enjoyment of what was done and this appears to be related to a greater engagement with lesson activities and to the higher autonomy they have been given. Teachers show appreciation for this kind of approach. Some students declare the intention to change their smoking habits.

Introduction

Adopting correct behaviours towards one’s own health and the environment depends on values, but also on everyone’s awareness of the consequences of these behaviours. Future citizen’s education must include information about these consequences to let everyone have tools and knowledge in order to decide how to behave. In the Italian secondary school health education (HE) and environmental education issues need more attention and integration with curricular science topics. Natural sciences teachers should address their effort in order to let students acquire knowledge and develop reflective skills which lead to responsible actions towards themselves and the environment.

Objectives

This study is a part of a PhD project which aim is to give indication to teachers on a possible alternative way of organising the teaching-learning process during science lessons so that it can lead to:

- integrate health education and environmental education / education for sustainability in the natural sciences (earth and life sciences) curriculum;
- increase interest and engagement during science lessons;
- promote students’ self-direct learning skills and autonomy;
- let students have a better understanding on how science work.
**Purposes of this study and research questions**

The aim of this study is to see how students and teachers react to a module that integrates health education with human biology topics using the problem-based learning (PBL) method. The research questions are the following.

- Which is the students’ feedback about a PBL experience used to integrate health education in a life science curriculum?
- What do teachers think about the method and its possible use?
- Could we expect any positive impact on students’ attitudes toward smoke?

**Rationale**

**Health education**


Viner & Barker (2005) stress that adolescence is a critical period for engaging the population in health as new behaviours are laid down and are maintained into adulthood and influence lifelong health. Neuroscience tell us that during adolescence brain undergoes important modifications (Rhoshel & Giedd, 2006), and according to Martin, Kelly, Rayens, Broglio, Brenzel, Smith & Omar (2002), sensation seeking, which is related more to pubertal stage than to the age itself, makes adolescents more vulnerable to nicotine, alcohol and drugs addiction.

These evidences show how much is important to deal with health education issues at the secondary school level. Knowledge of the physiological processes and awareness of the consequences that behaviours have on one’s own health might encourage people to avoid unhealthy habits. But, preaching what is good and what is not does not seem to be an effective educational strategy. School instruction should make possible the acquisition of scientific knowledge in a way that enables students to apply it for reasoning on the processes and the consequences.

**Problem-based learning**

The interest toward science is not high among young European people (European Commission, 2004; Sjøberg & Schreiner, 2005; OECD, 2008). Recent reports stress that for improving students’ engagement, teachers need to develop and extend the ways in which science is taught (Osborne & Dillon 2008) and suggest that the use of inquiry-based science education methods would improve student interest (European Commission, 2007).

An instructional method that could help in increasing students’ engagement would be the Problem-based learning (Barrows, 1986, 1998; Woods, 1995; Torp & Sage, 2002, Barrows & Wee Keng Neo, 2007). PBL can positively influence students’ motivation because, starting with a problem, students get involved in exploring the topic and in researching about it. Moreover it allows to develop self-direct learning skills (Schmidt, Vermeulen & van der Molen, 2006), and can give students the opportunity to better understand the nature of science. In addition, PBL can also help in developing argumentation skills, and science education research shows that argumentation is important for the appropriation of scientific practice (Jiménez-Aleixandre & Erduran, 2008).
In secondary school the authentic PBL has to be adapted at least because of the large number of students. The characteristics of PBL that have been kept in mind in the design of the instructional sequence are: students have to work also in small groups, the problem must be relevant, the teacher do not have to give lectures, students have to discuss among them and to search for information, and, of course, the topic must not be previously known by students. It is the problem itself that makes the students feel that they need to acquire new knowledge to be able to understand it, to give answers to questions, and/or to put forward possible solutions.

Health education issues can provide good scenarios for the PBL instructional approach, and the PBL could be an effective method to let students acquire knowledge related to the biology curriculum. This would increase students’ interest, and, at the same time, let them have more consciousness about healthy and unhealthy habits.

Methods

Participants, timing and data

During fall semester of the schoolyear 2008-2009, 81 students in four classes of Italian secondary schools (10th grade - 15 to 16 years old) experienced the module which will be described later on. Lessons, two hours per week, took place during a six weeks period and they were tutored by the author.

Students’ feedback was obtained by submitting two questionnaires. One, including multiple choices, yes or no, and open-ended questions, was submitted at the end of the module. The second one, containing a four-point Likert scale, was submitted a week after. Parts of the two questionnaires probed the same aspects to double-check students’ opinion.

The four biology teachers were asked to act as observers and take notes of single students and whole class attitudes. At the end of the module they were interviewed to obtain their feedback about the activities.

Instructional procedure and activities in the classroom

The module regarding anatomy and physiology of circulatory and respiratory systems was introduced with a scenario regarding cigarettes smoking. During the module, scientific concept weren’t taught prior to the discussion among students.

The main problem regarded the prohibition to smoke in public premises, and, during the all module, students were given different focused inputs aimed at promoting brain storming activities and at raising questions. Inputs used are the following:

• warnings and smoke compounds printed in cigarettes packages;
• experiments about solid particles and acidity of the smoke (Blonder, 2007);
• pictures of a smoker’s and a non-smoker’s lungs and heart;
• results of a smoker and a non-smoker arterial blood analysis;
• a text about cough of chronic smokers and whopping cough (pertussis);
• data about breathing and cardiac frequencies during sport practice.

All this lead to discuss about: anatomy of respiratory system; physiological processes which can explain each of the warning (e.g. ‘Smoking during pregnancy is harmful for the baby’); what kind of scientific researches warnings can be based on (scientific experiments and epidemiology); smoke components and their effects; different types of blood, gases transported, and haemoglobin; relation between breathing, blood circulation, and cellular respiration.
During each discussion, promoted by the input, some questions emerged, and eventually students, with the tutor’s help, chose what they thought to be important to learn and what kind of information they would need to search for the following lesson. Then retrieved information were compared and collaboratively elaborated within small groups (2-4 persons), and later presented and synthesized at the class level, with the tutor’s contribution. If information were considered incorrect or not exhausting, students were asked to go back to searching. Otherwise a new input was given to students. At the end of the module teachers submitted a test with open-answers questions for the assessment of content acquisition.

Results

The questionnaires were filled up by 81 students, with answers to 99% of multiple choice questions and 89% of open-ended questions.

The analysis of the students’ and teachers’ answers highlights the following findings.

Students’ contentment and engagement

We positively point out that 64% of students stated that they would like to use this method more frequently.

With regards to students’ motivation and interest, 58% of pupils think that the PBL approach can arouse more interest than the traditional method, while only 7% of them think the opposite. Moreover 80% of students consider interesting the activities proposed during the module.

An example of open answer is the following: “with this kind of lessons we were more interested and participated more. The whole class worked and in each workgroup everyone had his duty. Even people who usually don’t take part actively to lessons, gave their opinions and there was more collaboration among us.”. Another is “I liked that we started with a big problem and we ended up talking about a small thing like cellular respiration.” There are also some aspects that students dislike: “having more homework to do”, “having too much information to search”. But aspects they like are more frequent and deep: “having the possibility to express my opinion”, “being more engaged during lessons”, “looking for information by myself and not only studying on textbook”, “autonomy and responsibility given”, “reasoning on the topic”, “discussing among students and with the teacher”, “laboratory activities”, “having dealt with a topic of high concern to me”, “the health related topic”.

Some of these perceptions were confirmed also by the second questionnaire, which allows us to add / quantitative data. In this questionnaire students partially or fully agree with the following sentences: “module has been made more interesting than usual because of the scenario used to introduce the topic” (67%); “related social aspects helped me to understand the reason why we studied the topic” (72%); “the work done enabled me to learn scientific knowledge which can be applied to everyday life” (77%); “the discussion was important to improve my reasoning skills” (76%); “the topic was interesting” (77%); “I would like to treat more topics related to health issues” (73%).

All these opinions are likely to have had a positive impact on students’ engagement. In fact, about 65% of pupils said their participation was more active than usual, and 40% of them reported to have worked more than usual at home, while less than 20% declared the contrary.

Higher interest and participation, as well as less distraction, have been observed and reported also by teachers, especially for students who are usually lazier. Moreover all teachers acknowledged the positive response of students to this approach and they expressed the intention to use the method again (“often” or “sometimes”), because it may “improve students’ skills and autonomy”, “make them reflect”, “engage them in science studying”, even though they think that the development of a module with this approach takes more time than usual and they
could not always use it because of all the topics they are requested to accomplish according to the national biology curriculum.

**Impact on learning**

With regards to impact on learning, 61% of the students believe they can remember the topic better than usual, more than 86% think they have a sufficiently clear understanding of what they learnt, and 47% of pupils say that understanding was made easier, while 16% of them stated the contrary. They report difficulties in information searching (44%) and in selection and synthesis of the important aspects (26%). About the latter, however, they think that the method have been useful for improving the related skill (65%). Difficulties are reported also in open answers, where students wrote: “it is not very clear what we had to study” and “too much material made me confused”.

Teachers reported that results of the final text were in the average, but that some students who usually get bad marks achieved better results with this module.

**Attitudes toward smoking**

With regards to pupils’ smoking habits, there is evidence that shows that one third of the students of these classes smoke, although 30% of them smoke less than once a day. 24% of the smokers declared they will stop smoking while 44% of them declared they want to reduce the number of cigarettes they smoke.

It is difficult to foresee students’ attitudes in the long term, but it’s interesting to underline that 94% of the students say that after the module they know more than before about smoking consequences and 72% of them affirm that the module made them think about their attitudes towards smoke.

**Conclusions and Implications**

Results suggest that an health related issue and Problem-Based Learning approach can increase students’ interest and engagement during biology lessons. Teachers are aware of that, but they believe that the main obstacle for an extensive use of PBL is the longer time needed for this kind of approach, which contrasts with the number of topics included in the national curriculum.

It’s important to notice that students appreciated those aspects of the teaching-learning process that required a more active participation in which they feel more responsible of their own learning. However, further adaptation should be experimented to reduce the problems evidenced by students, especially concerning lack of clarity. This point can be critical in compulsory secondary school, where students are used to a teacher-directed method and may not have developed appropriate self-direct learning skills.

**Educational implications**

Difficulties may gradually be reduced if an active learning approach is used more often. A curriculum centred on abilities that students are expected to develop, more than on contents that they have to acquire, would allow teachers to a more extensive use of inquiry-based approaches.

At the beginning, to let students familiarize with PBL, teachers could:

- use smaller and more focused problems (Grover, 2004);
- give suggestions on where to search, but preferably only when students don’t find correct and exhaustive information;
- help students selecting and summarizing important information;
- can answer to specific questions, but only when students have already searched for information first.
Research implications

More studies should be done to test further adaptations of the PBL method which could reduce the difficulties encountered by compulsory secondary school students. Experimental studies would be needed to investigate the impact of these adaptations on contents and skills acquisition at the secondary school level.

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EFFECTING CONCEPTUAL CHANGE THROUGH TEACHING NANOTECHNOLOGY AND PERCEPTION

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Abstract

The particle theory of matter is not very popular with students and as has been shown in several studies it is not easy for students to come to an understanding. The difficulty is that students not only have to cross the borders between their life-world subculture and the scientific subculture, but the border to the other worldliness of the atomic world, too. This study suggests to advance students’ interest in and understanding of atoms by teaching nanoscience and the perception of properties.

Introduction

In science courses, students have to master the border-crossing between their life-world subculture and the subculture of science (Aikenhead, 1996). If the subculture of science fits with the students’ life-world culture, science knowledge will complement the students’ view of the world. When talking about facts of the submicroscopic world, the subculture of science is generally at conflict with students’ life-world culture. Due to students’ every-day experience, science courses about the character of the submicroscopic world are more like a jump to the moon than only into another subculture. Concerning the conceptual differences between daily-life and submicroscopic explanations, students are not only required to approach the border-crossing into the well defined system of meanings and symbols of the scientific community but also to understand the other-worldliness (Fladt & Buck, 1996) of the atomic world. Many studies (e.g. Pfundt & Duit, 1994) show that students usually superimpose the experiences they have learned in their world directly onto the submicroscopic world: ‘Atoms are of the same colour and do have the same temperature as the macroscopic material.’ Another aspect, which has frequently been observed, is that students believe that the space between the atoms in gases is filled with air or that it is continuously filled with the same substance which the atoms are made of when talking about liquids.

By using traditional teaching methods and explanations in school books, in many cases, it is not possible to give a sustainable idea of the scientific character of particles. Students think, the world, big or small, is exactly as it meets their eyes and fits their frames of reference. Between material properties and particle properties hardly any differentiation is made.

It might be possible to clarify the difference of material and particle properties and to widen and to enrich the rather prejudiced and narrow-minded view of the world by a new constructed teaching unit about nanotechnology and the perception of properties.
A teaching unit to facilitate the border crossing

In order to ease students’ border-crossing between everyday experiences and the character of the submicroscopic world, we have designed a teaching-unit which shows the students that there exist more worlds than only their own subjectively perceived one.

The central aspect of nanotechnology is to use the properties of small aggregations of atoms or molecules which are quite different from those of aggregations of bigger amounts. The change of the particle property appears at a size less than 100 nanometers (size effect). Students learn that reducing the size of particles causes a change of properties, sometimes continuously sometimes discontinuously.

Secondly, we help students to look back at their macroscopic world from a changed perspective. Their world, our world, is not just as they perceive it. Other beings living on different food sources and threatened by other natural enemies perceive their world, our world, quite differently from us, namely specialized in order to survive.

Our teaching unit named *The size is the kick!* has been constructed for basic-classes chemistry level 11, German Gymnasien (upper secondary school, 17- to 18-year-old students), which means nearly the third year of chemistry teaching. The teaching unit starts with an overview of ‘ancient’ nanoproducts (e.g. colloidal gold yields red stained glass) and current nanoproducts in common use and in advertisement. Students develop a size scale ranging from cosmic objects to atoms in order for them to develop an understanding of size differences. After that, the students get a survey about the *colour* as a property, its physical background, the size effect, different perceptions by human beings and animals. Other material properties like magnetism, durability and conductivity are introduced to the students in similar ways in the course of the unit. During the lessons, the students have to cross back and forth the border between the macroscopic and the submicroscopic worlds and the borders of the differently perceived macroscopic worlds. In the course of crossing the borders, these are always pointed out by the teacher. On this background, the change of the character of the particles by reducing the size and the different substance properties subject to the divers’ creatures, the students revise the history of the models of atoms, and discuss, if atoms need to be, as they are presented in the scientific models.

**Did the students cross the borders?**

The teaching unit was taught in eight basic-classes chemistry, level 11, German Gymnasium, to 150 students. Its efficacy concerning students’ achievement was tested in a classical test design.

The results of the test on student interest in chemistry and on their interest in this unit about nanotechnology (Tab 1) can be interpreted so far that students are more interested in the nano teaching unit than in their conventional chemistry classes. This corresponds with results by e.g. Bruns (2001) which show that traditional chemical subjects like the particle model, the production of metals and chemical reactions are considered less interesting than chemistry of the “everyday life”, such as, toxic gas, dynamite and pyrotechnics (boys), cosmetics, medicine and biochemistry (girls)). Yet, if you take into account, that nearly half of the teaching unit is devoted to size scale, different models of atoms and atoms’ properties, students’ interest most probably may not result, primarily, from those aspects that deal with nano science and perception.

**Table 1. Results of two questionnaires on interest evaluated with a 4-scale LIKERT-scale (high interest=1, low interest=4), Interest in (a) chemistry as a subject (Tepner, 2004) and interest in (b) the nano-teaching unit (own development) (N = 130 Students).**

<table>
<thead>
<tr>
<th></th>
<th>Cronbach’s α</th>
<th>Mean Interest (N = 130)</th>
<th>Mean Interest Girls (N = 90)</th>
<th>Mean Interest Boys (N = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest in chemistry as a subject</td>
<td>.94</td>
<td>3.12</td>
<td>3.19</td>
<td>3.04</td>
</tr>
<tr>
<td>Interest in the teaching unit</td>
<td>.73</td>
<td>1.92</td>
<td>1.84</td>
<td>1.96</td>
</tr>
</tbody>
</table>
The students’ answers to the open-ended items from the questionnaire: *What did fascinate you the most?* and *What do you think each student should learn?*, show that with the particular assembling of matter is not only interesting (29%) but, in addition, these facts about atoms are evaluated as important (25%).

### Table 2. (a) What did fascinate you the most? and (b) What do you think each student should learn?

<table>
<thead>
<tr>
<th></th>
<th>Percentage of N = 130 students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) fascination</td>
</tr>
<tr>
<td>The character of atoms.</td>
<td>29</td>
</tr>
<tr>
<td>The physical background and the perception of colours.</td>
<td>27</td>
</tr>
<tr>
<td>The basics of nanotechnology.</td>
<td>42</td>
</tr>
<tr>
<td>The risks of nanotechnology.</td>
<td>6</td>
</tr>
<tr>
<td>The perception of properties of materials.</td>
<td>16</td>
</tr>
<tr>
<td>Other properties.</td>
<td>4</td>
</tr>
</tbody>
</table>

The students’ fascination and their appreciation of the topic ‘atoms’ reflect their developing in understanding the character of atoms. The same result can be deduced from the answers to the third item from the open-ended questionnaire *What has changed in your belief about atoms?* (Table 3). Five typical student responses serve as categories for this part of the evaluation:

### Table 3. What has changed in your belief about atoms?

<table>
<thead>
<tr>
<th></th>
<th>Percentage of the students</th>
</tr>
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<tbody>
<tr>
<td>“Now it is clearer, that gold atoms have not a golden colour.”</td>
<td>11%</td>
</tr>
<tr>
<td>“How small and ubiquitous common atoms are.”</td>
<td>16%</td>
</tr>
<tr>
<td>“Now I know that our idea of the atom is only a model and that not everything can be explained exactly with it.”</td>
<td>20%</td>
</tr>
<tr>
<td>“That solid objects contain a lot of unfilled space.”</td>
<td>15%</td>
</tr>
<tr>
<td>“That I know more about atoms.”</td>
<td>12%</td>
</tr>
<tr>
<td>“Nothing.”</td>
<td>11%</td>
</tr>
</tbody>
</table>

### Conclusions

The results of the study on the teaching unit *The size is the kick!* show, that students are able to understand the differences between the characters and the properties of the macroscopic and the sub microscopic world and that they appreciate them as interesting and worth knowing. So we can conclude with the words of Marcel Proust (1871-1922) *The real voyage of discovery nanoscience and perception consists not (only) in seeking new landscape but in having new eyes.*


SUPPORTING TEACHERS TO TRANSCEND DISCIPLINARY BORDERS

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Abstract

Following changed perspectives in science education, German education policy has introduced output-orientated instruction and integrated science courses to their secondary schools. Current science teachers, however, have been confronted with these changes lacking support in coming to terms with the new challenges. Therefore, teaching materials were designed that address teachers’ need for support in (a) interdisciplinary issues and (b) output-orientated instruction. This paper presents the materials’ key elements for teacher support and introduces a joined study. Since teaching and assessing should complement each other, the proposed study will investigate ways to utilize the designed materials for diagnostic purposes as well. Therefore, it will compare students’ performance in hands-on-experimentation to those gained from paper-pencil-assessments with a specific test for experimentation abilities (NAW-test). As both measures build on the same theory it is expected to observe high intra-student-correlations between these measures. A pilot study was conducted to select the most suitable tests for the main study which will employ video-analysis alongside traditional paper-pencil-assessments. Experiments and tests have been found to work for the age group and tests are expected to do so after adjustments resulting from the pilot study’s findings.

Introduction

The IGLU-study of 2001 (the German equivalent to PIRLS) revealed for German primary students’ science achievements promising results ranking Germany sixth out of 27 participating nations (Bos et al., 2003). In contrast, PISA 2000, which examined 15-year-olds’ science-achievements turned out far more sobering results with German students crossing the line 20th out of 31 (OECD, 2001). It seems as if, in the progression from an integrated approach to science teaching in primary schools to Germany’s tripartite secondary science education (traditionally separate lessons in biology, chemistry and physics), the momentum of children’s curiosity gets lost. Therefore, most German federal states have introduced integrated science courses to the introductory stage of secondary school in order to bridge this apparent gap. Additionally, a changed perspective to teaching has moved German Educational policy to issue new standards (KMK, 2005a-c). These standards have been suggested to be orientated towards ‘competences’ (Klieme et al., 2003). Here, the term ‘competence’ subsumes those “cognitive skills and abilities to solve given problems, together with the motivational, volitional and social predispositions and abilities to successfully and responsibly employ problem solving in various situations” (Weinert, 2001, 27pp, my translation). In short: competences empower students to act rather than to just know.

Tackling these two aspects, demands from teachers to reach across boundaries between established disciplines as well as to view learning from a changed perspective (teaching to act rather than teaching to know). Since the typical German teacher has been trained in two science subjects at best but not in the full range of science subjects taught at secondary level, helping them to teach shared features of the sciences promises to draw on powerful synergies and, thereby, to advance students’ competences: A theoretical approach for e.g. experimentation...
(SDDS: Klahr, 2000) has already been translated into a simplified instruction paradigm which is arguably feasible in all science-subjects and reads: finding ideas/hypotheses – planning and conducting adequate experiments – concluding from experimental evidence (cf. Hammann et al., 2006; Walpuski, 2006). Thus, by not restricting experiments to one discipline but introducing them as mediating technique between sciences, learners will be equipped with a competently applicable method.

**Rationale**

In Germany, integrated science teaching still needs specifically developed teaching materials that help specialist teachers to convey ideas of science in general, orientating their teaching at the same time towards competences. Ideally, integrated teaching will preserve children’s curiosity and carry them eventually into their studies of the individual sciences. Yet, in order to facilitate this, teachers need support on different levels: (1) Current science teachers’ limited subject-training needs to be complemented by additional subject-information and methodological guidance in order to make teachers feel more comfortable even with unfamiliar content, while (2), regarding a competence-based perspective towards teaching, they need to be introduced to examples of how abstracted standards can be translated into concrete teaching.

Therefore, teaching materials that directly address these two issues have been developed and administered in integrated science classes at the introductory stage of secondary school. The materials’ aptitude to support competence-orientated teaching and learning as well as their diagnostic power regarding learning outcome in this field needs to be further investigated if one wishes to determine their instructional value.

**Methods**

Teaching materials for an integrated science course on ‘Water – The Many Faces of a Substance’ (Emden & Sumfleth, 2009a-c) follow up and build on a previous collection of similar materials (‘My Body and I on a Tour of the World’: Hübinger & Sumfleth, 2006). Both these compilations foot on a shared and – by 2009 – extended theoretical basis available for teachers (Hübinger, Emden, & Sumfleth, 2009), which is meant to introduce teachers succinctly to research findings that can help them tackling the new challenges of competence-orientated and integrated science teaching. At the core of materials, there is a table of competences that derives from the National Education Standards (KMK, 2005a-c). As these have been formulated in three individual subjects for students who are aged 16 but the materials, however, address 11- to 13-year-olds in a single subject, there was need to adapt the original wording of the standards. The result is a two-dimensional matrix that comprises on a vertical axis the four suggested major areas of competence: (1) employing science content-knowledge, (2) applying various modes to acquire science knowledge, (3) communicating science issues, (4) judging and evaluating science issues. Noted along a horizontal axis, there is a differentiation between three levels of abstraction as to account for a development of competence: (1) reproducing/identifying aspects relevant to a competence, (2) applying aspects of a competence, and (3) translating/employing aspects of a competence in new situations.

In the work-sheet-section of the materials there is always an assignment as to which competences (as indicated in the intersection of ‘area of competence’ and ‘level of abstraction’) can be addressed with a specific work-sheet. These work-sheets are always tied-in with a page of teachers’ commentary embracing additional information on: (1) specific learning goals, (2) solutions to the task, (3) subject-content background, and (4) methodological advice (s. Fig.1). By means of this design, teachers have the information necessary to help them in their teaching immediately available without needing to resort to additional handbooks or leafing back and forth through a booklet.
A related evaluation study will address the materials’ value for purposes of assessment. Derived from a notion of performance assessment (cf. Harmon, Smith, Martin et al., 1997), the study employs specifically designed paper-and-pencil-tests (NAW-test: Klos, Henke, Kieren et al., 2008) and video-analysis of experimentation-sequences (Walpuski & Sumfleth, in print). Pairs of students, negotiating solutions of science problems, will be video-taped while doing experimentation. These hands-on-activities typically pairs of students with scientific problems they solve relying on a limited array of experimentation materials (cf. ‘Interaction boxes’: Sumfleth, Rumann, & Nicolai, 2004). Video-analyses as well as achievement in the paper-pencil-tests will be measured according to students’ adherence to the simplified paradigm of experimentation (s. introduction). With both measures building on the same theory, it is expected to observe high intra-student-correlations between achievement in hands-on- and paper-pencil-activities.

**Results**

In a pilot study, 87 students from grade 6 (i.e. 12- to 13-year-olds) at German Gesamtschulen (≈ comprehensive schools) worked on the activities from five hands-on- and five paper-pencil-tests (NAW). These were thematically paired as to allow for later comparisons. Additionally, each student worked on a paper-pencil-test on prior-knowledge. Based on face-validation (cf. Pine, Aschbacher, Roth et al., 2006) it can be said that all the experiments work for the age-group, so that the decision which tests are to be incorporated in the main study needs to be made on basis of the results for the paper-pencil-tests (Table 1).

**Table 1. Results from paper-pencil-measures of the pilot study.**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Separation</th>
<th>Chemical Reactions</th>
<th>Surface Tension</th>
<th>Floating and Sinking</th>
<th>Water Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NAW (28 items each)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD = 4.09</td>
<td>SD = 5.44</td>
<td>SD = 5.33</td>
<td>SD = 5.17</td>
<td>SD = 4.37</td>
<td></td>
</tr>
<tr>
<td>α = .50</td>
<td>α = .81</td>
<td>α = .79</td>
<td>α = .65</td>
<td>α = .68</td>
<td></td>
</tr>
<tr>
<td>Ø rit = .033</td>
<td>Ø rit = .137</td>
<td>Ø rit = .119</td>
<td>Ø rit = .085</td>
<td>Ø rit = .070</td>
<td></td>
</tr>
<tr>
<td>diff.: .27 - .82</td>
<td>diff.: .17 - .89</td>
<td>diff.: .22 - .69</td>
<td>diff.: .24 - .79</td>
<td>diff.: .25 - .86</td>
<td></td>
</tr>
<tr>
<td><strong>Prior knowledge (6 items each)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD = 4.97</td>
<td>SD = 4.46</td>
<td>SD = 5.32</td>
<td>SD = 4.99</td>
<td>SD = 5.23</td>
<td></td>
</tr>
<tr>
<td>α = .74</td>
<td>α = .72</td>
<td>α = .79</td>
<td>α = .76</td>
<td>α = .75</td>
<td></td>
</tr>
<tr>
<td>Ø rit = .474</td>
<td>Ø rit = .452</td>
<td>Ø rit = .544</td>
<td>Ø rit = .501</td>
<td>Ø rit = .495</td>
<td></td>
</tr>
<tr>
<td>diff.: .43 - .64</td>
<td>diff.: .30 - .43</td>
<td>diff.: .34 - .46</td>
<td>diff.: .32 - .49</td>
<td>diff.: .36 - .53</td>
<td></td>
</tr>
</tbody>
</table>
Inspecting the test on prior content knowledge shows that each of the administered scales is similarly suited to be used in the main study (subsequent to minor adjustments to account for an increase in reliabilities (aiming at $\alpha \geq .80$) and wider distributions of item difficulties ($20 \leq \text{diff.} \leq .80$)). Looking at means and standard deviations, the test-scales on Chemical Reactions, Surface Tension and Floating and Sinking lend themselves most to direct comparisons and should, therefore, be retained.

Looking at the NAW-paper-pencil-tests, item difficulties show for all the tests good values and acceptable distributions. Average item discriminations suggest necessary adjustments to each of the tests aiming values $\geq .30$. Concerning reliabilities, the test on Separation fails the ultimate selection due to poor reliability ($\alpha = .50$). A choice between tests on Floating and Sinking ($\alpha = .65$) and Water Power ($\alpha = .68$) favours the former. Despite its marginally smaller reliability, actual experimentation in classes suggested that assessing students’ performances in Floating and Sinking could be facilitated more satisfactorily as raters, here, can distinguish more easily between the three aspects of experimentation. Considering all these aspects, the decision has been made to enter the main study with the test-couples on Chemical Reactions, Surface Tension and Floating and Sinking.

Conclusions and Implications

Aikenhead (1996) asks in his paper on border-crossing: “Could science curricula be developed for students identified by their border-crossing needs?” This study suggests addressing the question with a twist: As students enter secondary schools with no borders between the sciences, and as secondary schools seem to even generate these borders, science education might profit from taking secondary science teachers’ border-crossing needs seriously and support them in their professional development. This is especially true considering that giving science courses entails both: teaching and assessing. So, making teachers more comfortable and skilled in their teaching serves only half the purpose, supporting them to carry out just and reasonable assessments is certainly as important. Results from the study will serve to suggest directions for further research with suitable paper-pencil-based instruments for measuring performance in experimentation on a large-scale (NAW-test). Regarding the teaching materials, results will further serve to suggest an in-class-use of the suggested experiment for science educators to assess their students’ experimentation processes in a valid an economic manner.

References


COMPUTERIZED USE OF THINKING JOURNEY (TJ) MODE OF INSTRUCTION AS A MEANS TO OVERCOME STUDENTS' EGOCENTRICITY AND ENHANCE THEIR CONCEPTUAL UNDERSTANDING OF THE DAY-NIGHT CYCLE

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Abstract

The combination of the computerized Digalo (Schwarz & de Groot, 2007) as a graphical tool for representing argumentative moves in on-going e-discussions and the Thinking Journey (TJ) mode of instruction (Schur and Galili, 2009, Schur et al. 2009) were used. TJ enables students to get various perspectives on considered scientific concept. Thirty-two Grade 8 students from two junior-high schools participated in the study, which was conducted as a part of regular lessons in science. All students were requested to participate in small groups synchronous e-discussions on the concept of day/night along the TJ scenario. Results showed conceptual learning of the scientific concept. One could see that TJ interactions in the computerized version allowed students to mediate efficiently to their peers. The visibility of evidence in the TJ interactions used for the discussions lessened the egocentricity level since evidence and collective discussion was made part of the individual's cognitive space. By doing so, students could elaborate superior mental models. And indeed, we found a correlation of r=6.06 between egocentricity and mental model. Integrating between the argumentation idea and the Thinking Journey mode of instruction, enabled to establish focused mediation situations that enabled students to experience meaningful conceptual learning.

Introduction

The present study focuses on learning the concept of day/night cycle. It combines two kinds of activities, the first one of an argumentative character, and the second one of an inquiry-based character. Inquiry-based activities are realized through the consideration of multiple perspectives in argumentative moves mediated by the teacher, with the use of the Thinking Journey mode of instruction (Schur et al. 2002; Schur and Galili, 2009, Schur et al. 2009).

Rationale

Thinking Journey and multiple perspectives

The Thinking Journey method (Schur and Galili, 2009; Schur et al. 2009) is especially designed to overcome problems of egocentricity in science education. Thinking Journey (TJ) approach incorporates the features of mediated learning as well as of the constructivist paradigm (conceptual change). The approach suggests variation of learner's perspective on the natural phenomenon learned, instead of unique perspective, common in teaching practice. Changing perspectives allows students to overcome their naïve knowledge usually based on the intuitive egocentric view. A teacher-students discussion takes place addressing images of the considered phenomenon, taken from several perspectives, often never seen before by the students. The teacher mediates the particular scientific conception to the students who usually hold their own ideas at odds with the scientific knowledge. Mediation, that is to say, bridging between the two types of knowledge, draws on revealing of these ideas, as well as of other
possible cognitive difficulties of the learners in real time. Introduction of multiple perspectives prepares conceptual change and construction of certain scientific concepts by the learners. Students are guided to identify the considered concept in its several manifestations in different environments. The mediation of the tutor is intensive; it complies with the principles of mediation articulated by Feuerstein and colleagues (Feuerstein, 1990; Feuerstein et al., 2006).

**Computerized mediation**

The Digalo application was used to provide an electronic medium for sustaining collective argumentation. In a recent study, Asterhan, Schwarz and Gil (submitted) showed that in the case of electronic collective argumentation (in which each student had its own computer, and was participating in a synchronous discussion with the other students and the teacher as a mediator), most students find computer mediation absolutely necessary. According to Asterhan and colleagues, students’ specific needs are related in the mediation during the discussion. The mediation should aim at deepening and maintaining focus, supervising and aiding in technical problems, while not imposing ideas. In this study we examine the mediation types (managerial or content, personal or general, wide or focused) on the amount of student's reactions, and their quality (superficial or deep).

**Methods**

We inquired two research questions, in two different and, to our view, complementary methods:

1) Did the computerized TJ day/night cycle trigger conceptual learning?
   
   This question was tackled according to five aspects:
   
   a. Correctness of knowledge: Did student's knowledge of the day/night cycle improve?
   b. Elaboration of the answers: Did answers become more elaborate?
   c. Mental model: Did mental models of the day/night cycle progress?
   d. Egocentricity: Did egocentricity in viewing the day/night cycle decrease?
   e. Simplicity: Did answers become simpler and more parsimonious?

2) How does mediation effect students' construction of knowledge through argumentative activities?
   
   This question is being tackled according to two aspects:
   
   a. What was the role of mediation in the group discussions?
   b. Are there actions or patterns of actions for mediating synchronous discussions of Thinking Journey interactions?

**Method**

**Participants**

32 8th grade students (ages 14-15) from 3 different classes in two schools in Jerusalem took part in the experiment. All students mastered basic computer tools (Office, internet). The study took place as a part of the regular science classes throughout the school year. Each class (of about 30 students) was divided into two cohorts; each cohort was further divided into groups of 3-4 students. The classroom activities were led by the teachers. As aforementioned, the teachers were all experienced and highly motivated. The four teachers attended the seminar for learning how to work with the computerized version of the Thinking Journey.

**Tools**

The first tool, a questionnaire including knowledge items and questions in which students were requested to explain day and night phenomena. The second tool consists of the Digalo graphical tool for representing collective argumentation. The third tool consists of the Thinking Journey computerized interactions. It comprised of computerized worksheets and pictures of day and night on the earth and the moon from different perspectives. The computerized version of TJ for teaching the day-night cycle that is used also in this current article is presented in (Schwarz et al. 2009).
Collection and analysis of the data

All questionnaires were collected and argumentative maps were recorded. All lessons were video-taped.

Correctness

The grades for the correctness variable ranged from 0-2.

0 – incorrect answer

For example: Q: Are there day and night on the moon?

A: No, there is only night on the moon, because it’s dark.

1 – partly correct answer

For example: Q: How would you explain to a friend the day and night phenomenon? A: The earth revolves around itself and around the sun. When the earth revolves, and a certain area is not lit, the sun begins to light it, since the earth also revolves around itself. (The answer is only partly correct since it involves the fact that the earth revolves around the sun, which is not relevant for the day and night cycle).

2 – Correct answer.

For example: Q: Are there day and night on the sun?

A: No, the sun is the source of “day”, and this is why there is no night there. It is always lit, so there is always “day” there, and no “day and night”.

For the grades of elaboration, we formed a check list of ideas that need to appear in each of the questions to receive a full answer. Each phrase received one point. Each missing or incorrect phrase that was added received zero points. We summed the number of points and divided it with the number of total needed phrases for a full answer + the incorrect phrases given by the student.

For example: Q: Explain in your own words what are day and night

Ideas checklist-

- The sun lights (on the earth)
- Day and night exist in different areas of the same celestial body
- Day = light
- Night = darkness
- The moving from day to night is created by the fact that celestial bodies revolve around themselves.

Mistakes- any other idea (contradictory or irrelevant)

Grades for elaboration will be exemplified further on.
**Simplicity**

The simplicity of the explanations expressed to what extent explanations for the day/night cycle became more similar when describing the day and night on earth, the moon, mars and other planets. We identified 4 levels of simplicity translated into grades for simplicity ranging from 0 to 3.

0 – Different answers: a different explanation of the same phenomena for different planets
1 – Non contradictory answers: An explanation to at least one planet and the rest is not contradictory (lack of knowledge, indecision).
2 – Identical explanation for at least two planets: the same explanation for two of three planets (earth, moon, mars).
3 – Identical answers for all of the planets: the same explanation for all planets and a different explanation for the sun.

**Identifying mental models**

We analyzed all explanations provided by the students and analyzed their content in order to identify the mental model of the students. We identified six explanatory frames of the day/night and day cycles.

No model
The sun revolves around the planets
At day the earth revolves around the sun and at night around the moon
The earth revolves around the sun
The earth spins, and the sun and moon are in two opposite sides of it
The scientific model

Two judges compared each of the explanations written with the explanatory frames proposed and either recognized one of them or decided that it was impossible to classify the explanation. For most of the explanations, judges recognized a suitable explanatory frame and agreed upon it. Although there was certain variability in the explanatory frames that the students used, it was possible to maintain an agreement between the judges with Cohen kappa of 0.9.

**Identifying level of egocentricity**

We analyzed all the explanations given by students in their questionnaires to identify something else from mental models or explanatory frames, the way people saw themselves in the day/night cycle, or what we called their level of egocentricity. Six levels could be identified:

(a) Looking only at oneself on earth, without viewing it as a sphere;
(b) Day and night can only happen on earth;
(c) Day and night can only happen in the earth's environment;
(d) Ability to see the phenomenon as happening in distant planets that are similar in a trait (being lit) with no explanation;
(e) Partially understanding the law – there is a theoretical explanation which is not correct/incomplete;
(f) Understanding the law in a scientific manner.

An example of level of egocentricity is given further on.

Example of an analysis of the questionnaire:

To better explain how the analysis took place we bring you an example of a questionnaire in which all variables were measured:
An example of analysis of data:

We bring an example for analysis of data. It will be a full analysis of the pretest – in order to demonstrate how to calculate and determine the grades for each variable.

Example 1:

Details of the questionnaire:

1) Q- Define in your own words what are day and night
A- Day is when the sun light the area where the state is, night is when the sun lights another place (area) in the world, so that the sun lights cannot illuminate this area. This happens when earth revolves around itself and around the sun.

Correctness: the grade is 1, since the answer is partly correct and partly incorrect.

Elaboration:

Phrases checklist-

- The sun lights (on the earth) - V
- Day and night exist in different areas of the same celestial body - V
- Day = light - V
- Night = darkness - V
- The moving from day to night is created by the fact that celestial bodies revolve around themselves - V
Mistake – Linking the day and night phenomena to the fact that the earth revolves around the sun – X

Calculation of the grade –

5 correct answers out of 6 ideas (one incorrect) – 5/6= 83.3%

2) Q- How would you explain to a friend the reason why day and night happens?
A- The earth spins around itself and around the sun. When the earth spins, and a certain area is not lit, the sun begins to light it due to the fact that the earth spins around itself. When the earth spins the area of the state that was towards the sun (lit) turns with its "back" to the sun, and becomes night instead of day.

Elaboration:

Phrases checklist-

- The sun lights (on the earth) - V
- Day and night exist in different areas of the same celestial body - V
- Day = light - V
- Night = darkness - V
- The moving from day to night is created by the fact that celestial bodies revolve around themselves - V
Mistake – Linking the day and night phenomena to the fact that the earth revolves around the sun. – X

Calculation of the grade –

5 correct answers out of 6 ideas (one incorrect) – 5/6= 83.3%

Correctness: the given grade is 1, since the answer is partly correct and partly incorrect.

3) Q: Are there day and night on the moon? Explain.
A- The moon revolves around the earth, and the earth around the sun, so when the moon is between the earth (and the sun), it is lit and there's day. When the moon isn't between the earth and the sun but behind the earth, the sun light doesn't reach it and there's night.

Elaboration:

Phrases checklist:

- The moon revolves around the earth and the sun lights it when it is between the earth and the sun – V
  - Day and night exist on the moon - V
    - Day = the moon is lit - V
    - Night = the moon is dark – V
  - The phenomenon is caused by the sun lighting the earth – X
- A lack of connecting between day and night on earth and on the moon – X

Mistakes – connecting day and night on the moon with eclipses of the earth – X

Calculation of the grade –

4 correct answers out of 7 ideas – 4/7 = 58%

Correctness: the given grade is 1, since the answer is partly correct and partly incorrect.

4) Q- Are there day and night on Mars? Explain.

A- If Mars revolves there are day and night, since rays from the sun reach it, and if it doesn't revolve, then there's always day at one place and night in another.

Elaboration:

Phrases checklist:

- Mars spins around itself - V
- Day and night exist on Mars - V
  - Day = Mars is lit - V
  - Night = Mars is dark – V
- The phenomena is identical to the one that happens on earth – V

Mistakes – Since there is an understanding of how the process works and just a lack of information on whether mars spins, we didn't consider it as a mistake.

Calculation of the grade –

5 correct answers out of 5 ideas – 5/5 = 100%

Correctness: the given grade is 2, since the answer is correct.

5) Q- Are there day and night on the sun? Explain.
A- There is always day on the sun, since the sun sheds light, which creates day. There's always light on the sun so there's always day.

**Elaboration:**

**Phrases checklist:**

- The sun is the source of light - V
- Not saying that the sun spins (in connection with the change of day and night) - V

**Calculation of the grade –**

2 correct answers out of 2 ideas – 2/2 = 100%

**Correctness:** the given grade is 2, since the answer is correct.

6) Q- Is the day and night phenomena unique to the earth? Explain.

A- No, it exists in any planet that revolves around itself and around the sun.

**Elaboration:**

**Possible correct answers (choose at least one):**

- Happens in all planets of the solar system
- Exists in any place that the sun lights
- Examples for other planets in which day and night exist
- Happens on every planet that spins around itself - V

**Mistakes –** Linking the day and night phenomena to the fact that planets orbit around the sun - X

**Calculation of the grade –**

1 correct answers out of 2 ideas – 1/2 = 50%

**Correctness:** the given grade is 1, since the answer is partly correct and partly incorrect.

**Mental model** – The mental model that arises from all of the student's answers is one that links the day and night phenomenon to the fact that the earth/planets revolve around the sun. This is why the chosen mental model is the fourth one.

**Egocentricity** – it seems that the student in the example has a way of explaining the day and night phenomena in a way that is sometimes similar and sometimes different on the earth and other places (mars and moon), and does that with a clear explanation/rule – day and night happens in any planet that revolves around the sun and around themselves. Since there is a rule that is not fully correct but applicable for explaining the phenomena in many settings the chosen egocentricity level is 5.

**Simplicity** – the student gave the same explanation (planets that revolve around the sun and around themselves) to two of the three planets in the questionnaire – the earth and Mars. The moon received a somewhat different explanation, involving eclipses from the earth as a reason for day and night. This is why the grade for simplicity is 2.
Analysis of the discussions

The second research question related to the analysis of the discussions that took place in the various groups. We have examined the influence of the mediation on discussions according to the following parameters:

**Mediator:** teacher or experimenter.

**Location of contributions in the discussion:** Beginning, middle, end

**Type of reference:** General – to all participants, Personal – to a specific participant.

**Type of relatedness:** Wide – relating to the wide topic of discussion, focused: relating to a specific point in the discussion.

**Number of students to which the mediation move is directed**

**Quality of students’ interventions:** Shallow - unserious or irrelevant interventions to the topic, Deep – a serious and related interventions to the topic.

**Type of mediation:** Content – relates to the topic of discussion (Such as when the teacher asks if it is day or night in the presented picture), Organizational – relates to aspects such as encouraging students to participate, and a correct implementation of the task (such as when the teacher asks the students to focus on the main question, and not to relate to personal matters etc.).

The analysis of variables was qualitative (such as the type of mediation – organizational or content) and were evaluated by two judges using agreed upon rules (in the case of the mediation type – checking if the mediation move deals with the topic of discussion or with maintaining the discussion). The inter rater variability was high (Kappa = 0.9).

**Results**

In order to check whether there were differences between classes before the activity we conducted a MANOVA analysis. There were no differences between the classes prior to the activity in any of the independent variables.

Another MANOVA of 2 (class 1, 2)* 2 (time – before, after) *3 (mediator – none, teacher, experimenter) was conducted in order to confirm the first research question. Results showed an improvement in all dimensions of the first research question following the Thinking Journey activity, except for the correctness of the answers that showed only a tendency towards improvement ($F = 3.61, p = 0.068$). Students’ answers were more elaborated ($F = 7.85, p = 0.009$): students knew more correct details after the activity compared to the situation before the activity. Most students (over 60%) did not hold the scientific model after the activity, a fact which explains why not all answers were correct. Still, there was an improvement in the model ($F = 7.64, p = 0.01$), which is a substantial progress in the structure of knowledge that was obtained through argumentation in the TJ interactions. There was an increase in the universality of the day and night concepts following the activity ($F = 18.40, p < 0.001$) – students could see it as less related to the earth and more general. A correlation between the type of mental model and
egocentricity was also found ($\text{RPearson} = 6.06, p < 0.001$), so that the less egocentric someone is, the more advanced is his/her mental model. No effect for class or group was found. Finally, students answers became simpler and more parsimony ($F = 4.64, p = 0.041$), and they gave closer explanations to the same phenomenon in different contexts. The results of the first research question brought good news: conceptual learning of a scientific concept in an environment integrating argumentation with TJ mediated interactions.

In relation to the second research question, we also analyzed the mediation moves, (such as presenting the main questions, challenging students’ views, encouraging participation, focusing the discussion, enforcing the discussion rules) in the discussion by the following parameters: Mediator, Mediation type (content/organization), Location (beginning/middle/end), Type of approach (general/personal), Type of relating in mediation (wide/specific), Directedness of the teacher, and Quality of interventions of students (deep/superficial).

The findings show that there was no effect of the location of the mediation on the quality and number of responses it received. Also, all mediators were very active in all parts of the discussions, and their involvement was in many times crucial for the continuation and development of the discussion. The mediation moves that dealt with content (referred to the task) received deeper responses ($F = 22.24, p < 0.001; \text{Beta} = 0.405, p < 0.001$) but fewer responses ($F = 29.66, p < 0.001; \text{Beta} = -0.263, p < 0.001$) as compared to organizational mediation moves. The same is true for a personal approach in mediation, which received deeper responses ($F = 22.24, p < 0.001; \text{Beta} = 0.371, p < 0.001$) but fewer ($F = 22.24, p < 0.001; \text{Beta} = -0.495, p < 0.001$) as compared to a general approach. Finally, wider mediation moves received deeper ($F = 22.24, p < 0.001; \text{Beta} = 0.326, p < 0.001$) and more ($F = 29.66, p < 0.001; \text{Beta} = -0.432, p < 0.001$) responses than a specific approach.

The second research question enabled us to see that mediation was essential for the continuation of the discussions. If the mediator focused on content it enabled the students to better understand the concepts, but organizational mediation enabled the students to get more responses. The ability to focus the mediation towards specific students enabled students to give deep responses. When the mediators were able to see the wide picture of the conceptual development they got deeper responses from the students.

Examining a mediated discussion

We are bringing a discussion with human mediation in order to show the details of TJ interaction in the classroom with the use of computers and with the Digalo as a monitor of the discussions. All the dialogues were written on the computer screens by the students and the mediator and sent to the other members of the same group. All the discussion maps were saved.

The following discussion starts with each of the students observes a picture of the earth seen from the moon. The moon's surface is lit, and the students of the group are asked to determine whether there is day or night on the part of the moon seen in the picture. As the sky of the moon is black (there is no air there), and the earth seems close to the moon in the picture, students find it difficult to determine if it is a day on the moon. According to the TJ idea, this is the first picture presented to the students in the course of their learning about the day-night cycle. The faraway environment enables students to ask questions and to try and orient their way through the use of scientific principles.

In this discussion, the mediator was an experimenter. Two students, Ortal and Ariel, participated in the discussion. Ariel gained the highest grades for almost all variables even before the activity, and stayed the same after it. Ortal improved on correctness of her responses, egocentricity and mental model.
Discussion

1) Mediator, Question, *is there day or night on the moon in the picture?*

2) Ariel Opinion, *there’s day in the picture* (link to 1, support to 7)

3) Ortal, Opinion, *you can’t tell from the picture* (link to 1, object to 2)

4) Ariel, Question, *why?* (link to 3)

5) Ortal, Explanation, *because you can’t see that there’s light. The light can come from the camera* (link to 3, 4, object to 7)

6) Mediator, Question, *why do you think so? What in the picture made you think so?* (link to 2)

7) Ariel, Explanation, *because there’s light on all of the moon, (not including shadows from the mountains) so I don’t think it’s from the camera* (link to 6)

8) Mediator, Question, *which camera?* (link to 5)

9) Ortal, Explanation, *the one they took the picture with* (link to 8)

10) Mediator, Question, *you say on the one hand that you can’t see there’s light, but on the other hand, you say that there’s light that may be coming from the camera? What do you think, is there light or not?* (link to 5)

12) Ortal, Explanation, *there’s light, not day* (link to 6)

14) Ariel, Opinion, *the sun* (link to 10)

15) Mediator, Question, *the light doesn’t come from the camera’s flash* (link to 9)

16) Ariel, Comment, *is that a question? Because I don’t think so, and it’s in a form of a question* (link to 15)

17) Mediator, Comment, *it’s a comment, not a question* (link to 16)

19) Mediator, Question, *Ortal, if I tell you that the light doesn’t come from the camera, will you still think that you can’t tell if it’s day or night?* (link to 9)

20) Ortal, Question, *so where does it come from?* (link to 18)

22) Mediator, Question, *what do you think?* (link to 18)

23) Ortal, Opinion, *yes* (link to 19)

24) Ariel, Opinion, *from the sun, like it was in the last picture* (link to 20)

25) Mediator, Question, *and what would be your answer?* (link to 22)

26) Mediator, Question, *so why is the sky dark?* (link to 24)

27) Ortal, Opinion, *’cause it’s night* (link to 25)

28) Ariel, Explanation, *as in the last class, I think that since there is nothing, then there’s light only on objects* (link to 26)

29) Ortal, Opinion, *since space is empty* (link to 26)

30) Mediator, Question, *what makes you think it’s night?* (link to 27)

31) Mediator, Question, *I ask from each of you to write a final answer, do you think that there’s day or night on the moon in the picture, and explain why*

32) Ariel, Opinion, *day – I think since there’s nothing-empty, so there’s light only on objects* (link to 31)

33) Ortal, Argument, *There’s day on the moon, because you see light* (link to 31)
The discussion begins with a presentation of the main question in a broad and general manner (contribution 1), which receives different replies from the students. Ariel claims it is day (contribution 2), while Ortal claims there is no way of telling from the pictures (3). This forces the mediator to move to more focused and personal mediation, in order to challenge each student in his/her own position. Ariel is being asked to explain and elaborate his response (6), and Ortal is being asked to explain hers – which camera is she referring to (8). In the mean time, the students communicate among themselves (contributions 4, 7). A following interaction on the existence and source of light is raised. The mediator tries to check a possible contradiction to Ortal’s claims: on the one hand she says there is no light and on the other hand she speaks of light from the camera (10). Ortal explains she meant that there is light but not day (12). Ariel replies to the question on the source of light, and says to Ortal he doesn’t think it comes from a camera (14, 24). The mediator agrees and gives Ortal a piece of information – the fact that the light doesn’t come from a camera (19). In parallel, the mediator challenges Ariel’s answer that there’s day by asking why the sky is black (26). Both students reply to this question (28, 29), and when asked to give their final opinions they both agree that in the picture, there is day on the moon (32, 33).

A good mediator through the use of computers is not different in the general features from a face to face one. He has to deal with a lot of demands at the same time: to be alert, organize the discussion, to respond quickly, understand the students’ needs and, scaffold learning. The most important feature of a good mediator is to be able to listen carefully to the place of the learners and to respond on time to their specific needs.

The analysis of the discussion shows that good mediation calls for flexibility from the mediator. The mediator needs to have a quick understanding of the students’ needs and responding to them, as happened in the discussion, where the mediator reacted quickly to the students needs, according to their pace. When this type of flexibility is missing, and the mediator responds mostly to one student, and there are other students who need his feedback and guidance, the discussion may get stuck. It seems that generally, a good discussion needs to begin with a general and broad presentation of the topic/question, and observing students’ replies and condition. In the case of consensus between students, the mediator should continue deepening and elaborating their understanding, and challenge everyone with broad and general mediation contributions. In the case of disagreement, as in the example we showed, there is no choice but to move to a focused and personal mediation that forces the mediator to relate and challenge each student separately. Still, a cooperation and discussion between the students themselves should be encouraged, and the mediator should try to support mutual questions and debate between them.

Conclusions and Implications

General discussion

The present study has shown that a complex environment based on argumentative and Thinking Journey mediated interactions can lead to conceptual change in the understanding of students of the day/night cycle concept. The research was not designed according to an orthodox experimental setting but rather was quasi-experimental. For example, we did not compare the effects of the use of Digalo to face-to-face discussions. The success of this experiment is in itself very important because it shows the tangibility in the use of complex environments integrating enquiry (TJ mediated interactions) and argumentation for learning scientific concepts. Egocentricity level was lowered by presenting multiple perspectives and discussing them. The visibility of evidence and of discussions could lessen egocentricity level since evidence and collective discussion was made part of the individual’s cognitive space. By doing so, students could elaborate superior mental models. And indeed, we found a correlation of r=6.06 between egocentricity and mental model. One can consider that this result can be explained from the specific way in which TJ mediated interactions are constructed to enable students to observe phenomena from a variety of perspectives and to connect scientific concepts with observation of specific environments.
Teachers and students' mediation

Teachers had difficulties in mediation through the use of computers. In oral discussions, teachers are able to react very quickly but in e-discussions where they have to write their interventions they have difficulties to engage. In addition, it was very difficult for the teachers to identify students’ mental models on the computer's screen in order to focus their teaching actions.

Concerning spontaneous mediation by peers, the fact that the environment invited collaboration, the fact that students felt that they were not supervised, invited them to organize themselves. This unexpected finding of spontaneous role taking of organizing synchronous e-discussions is worthwhile further research. It is worthwhile noting that TJ interactions are constructed in a way to enable peer mediation. The computerized version of TJ allows students to listen more carefully to each other and react in real time, as it takes more time to write down their words than to say them aloud, so they have time to react to their friends before answering.

Students' conceptual difficulties and the process of conceptual change

In the mediated discussion we described above and in the answers of students to the pre and post questionnaires, it was possible to peek at processes that students undergo when learning scientific concepts. Two obstacles and their overcoming were salient. The first concerns the difficulty students have to understand that a scientific principle can be used to explain different phenomena: Students that could explain the day-night cycle on earth had difficulties in understanding that the same principle governs what happens on the moon. Explaining the day-night cycle on the moon through an eclipse of the earth is commonplace, and suggests the need to teach scientific principles in a variety of contexts, since each context challenges students and often leads them to give erroneous answers (see also Schur, Galili & Shapiro, 2009 for the earthy perception of students of day-night cycle and Schur & Galili, 2009, for the earthy perception of students of gravity and weight). Of course this tendency to stick to one familiar context naturally led to the second obstacle in learning the day and night cycle, egocentricity. Many Grade 8 students thought that the day-night cycle exists only on earth. Others said that the moon is always dark, because "it appears only at night". Others said that there is no day-night cycle on mars and on the moon because they are "outside of the earth's range". The Thinking Journey approach meets students with other contexts and the teacher's mediation helps in integrating these different contexts, leading to the elaboration of the scientific principle that stands behind the day-night cycle. Students could explore views of the day-night phenomenon in a variety of astronomical environments such as the moon, mars and the earth. The use of visual images enabled them to learn essential features of the concept and to see how the same phenomenon is seen differently in different places. Students compared the various environments with that of the earth and the mental voyage to other celestial environments enabled them to get out of their egocentric understanding of the day-night cycle and to adopt a universal point of view. Naturally, their explanations turned to simpler and less context-bound.

References


MEANING MAKING WITH LIVING ANIMALS:
HOW TO GET FROM OBSERVATIONS TO EVIDENCE?

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Abstract

This paper integrates two main parts of science education — respectively teaching in general: first, a theoretical approach and second its practical application. In order to proceed from at first often ‘naïve’ observations of animals to evidence based ‘scientific’ knowledge building, a model is used as a theoretical framework. After the introduction with a more general focus on practical work and its role in science education, this model is described (based on theoretical fundamentals of motivation and interest). Furthermore, this approach is the basis for theoretical guided practical examples of implementing the transition from ‘naïve’ observation into ‘scientific’ evidence in science teaching by using living animals. However, even if the impact of the “real” within science teaching is beyond debate and personal reports of teachers as well as newer empirical research strengthen this point of view, it is important to ensure very high quality instructions during lessons with living animals. This is a multidimensional task with several specific aspects e.g. regarding the care for animals, the structure and aim of the instruction, the role of student’s activities etc. To illustrate this, selected practical examples which cover a wide spectrum of applications in biological education are presented, too.

Introduction: practical work, cognition and construction

General aspects of practical work in science education

Meaning making with living animals does implicate practical work in class, lab or outdoor. Within science education, the relevance (and the problems) of practical work has been a debate since the very beginning of a discourse about science teaching itself and it is discussed from several points of view up until now. As many other times before, just recently the effectiveness and the lack of conceptual understanding is discussed critically (Abrahams & Millar 2008). Anyhow, the meaning of – especially theoretical driven – practical work and its necessity is beyond debate (Roberts 2002). Even computer-aided instructional settings did not replace practical work or contact to real objects at all, for example Whitelock & Jelfs (2005, S. 123) pointed out that “…when it came to dealing with rock samples, students wanted to handle the real thing.” Not only out-door or out-of-school learning environments have to provide authentic (in sense of practical) work in their ‘science curricula’ (c.f. Tranter 2004, Braund & Reiss 2006). Another close related aspect of practical work and the ‘authentic aspect’ – using first- vs. second-hand data in chemistry – is discussed by Hug & McNiell (2008).

The relevance of practical work, authenticity and experience in biological education is a main issue in recent research: there are several examples, e.g. building knowledge about ecosystems and its animals (‘reading’ nature) (Magntorn & Helldén 2005, 2007), learning about adaptation of animals (Klingenberg 2007), the relevance of animals in lessons (Prokop et al. 2007) or reducing misconceptions of animals through every day contact (Prokop et al. 2008). Therefore, the most important demand of biological education is reconnecting “…students with the natural world at first hand” (Tunnicliffe & Ueckert 2007).
Cognition and construction: a field of discussion in science education

First hand or practical work might not only be an issue of gaining knowledge in cognitive ways by changing naïve observations (pre-concepts) into scientific understandings (elaborated concepts) (usually most authors refer to the Cognitive Change Theory ‘CCT’ by Posner et al. 1982). The discussion about potentials and limitations of this (and other theories) has larger dimensions and it is affecting seriously the building and the use of theory in science education as well as the ‘modern’ way of regarding learning, the constructivist perspective. Especially the use of theory in science education and the ‘constructivistic’ driven research was basically attacked by Abd-el-Khalick & Akerson (2006).

Of course it is impossible to lay out the discussion here, to be very short (and therefore in some terms ‘incorrect’): Abd-el-Khalick & Akerson (2004) suggested a new concept, because “Learning ecologies [the name of the concept, KK] was more a statement of frustration about the current status of CCT, than an attempt to crowed the literature with one more construct.” (p. 188). It should be emphasized here, that the concept was not suggested as a new ‘theory’, nor there was a claim “…to abandon CCT because it remains a useful theory” Abd-el-Khalick & Akerson (2006, p. 188). With focus on the multidimensional approach and the here presented model (see below) it seems to be important to take a closer look on theory use itself as this is done by the cited authors, too: “Dressman (2005) examined the use of theory in about 70 purposively selected studies published in premier literacy research journals. He found that the larger majority of the examined studies used theories, at best, uncritically to support the premises, rather than the full activity, of the research.” (p. 189). After some more detailed critical examinations and further comments on the use of theory in general and, respectively, in educational science, Abd-el-Khalick & Akerson also pay attention to ‘constructivist theories’: “Yet, unlike what a robust theory of learning would do, constructivism exclude very little in terms of the plausible explanations for learning. Indeed, constructivism has a variant for every possible explanation of learning […]. Not only does constructivism fail to restrict plausible explanations of learning, it also fails to functionally restrict what could pass as constructivist teaching. A quick survey of different ‘constructivist’ learning approaches or what is usually passed as “constructivist teaching” would suffice to drive this point home.” (p. 189). This critique does not stand alone; a number of educational scientists have already become doubtful, if ‘constructivists’ really bring new ideas into education and educational science. This perception was clearly stated ten years ago by Terhart (1999, p. 645): ‘constructivist education’ offers neither “…really new forms for the educational work” [„…keine wirklich radikal neue Formen für die Praxis des Unterrichtens anzubieten”], nor are there distinct characteristics (Abd-el-Khalick & Akerson 2006, p. 189). After this rather critical review of theory use in science education, in the next chapter we will at first take a look on a model of motivation and furthermore on the interest-construct. Both can be taken as a fundament of exploring activities. Afterwards the ‘explore-compare-square’ as a model for exploring nature, respectively animals, will be presented.

Theoretical background

Constructs for bridging the cognitive/affective gap: motivation and interests

Learning – in sense of building (‘constructing’) knowledge and understanding as well as changes in attitudes – is inseparable a combination of cognition, motivation and interests (and maybe more, not well defined constructs of mental states). Because of limited explanation scales from solely cognitive driven theories or models (e.g. CCT) it is necessary to take also in account the motivation and interests individuals have during a learning process.

Emotional aspects of learning and the cognitive model of motivation

A broader understanding of learning and emotions can be seen by Mayring & v. Rhöneck (2003): they focused on ‘Learning emotions’. Alsop (2005) claimed for research ‘beyond Cartesian dualism’ in science education. Nevertheless, cognition and motivation were already linked together in an elaborated way 25 years ago by the ‘enhanced model of cognitive motivation’ (Heckhausen & Rheinberg 1980) (Fig. 1).
Basically, the model is structured by three levels: the episode-level (or ‘episode’)-structure: what a person does in a situation), the expectation-level (what a person expect from the action/learning) and the stimulus-level (external activity- and consequence-stimuli). This last level is the ‘enhanced’ part of the model and it was introduced later by Heckhausen & Rheinberg, because they observed behaviour, which is not necessarily promoted by the expectation of action/learning or within the four steps of the episode-structure. In other words, some of our behaviour does not have the need (or at least: it seems to have no need) for an expectation('-stimulus'). The stimulus for those activities lies in the performance itself (some examples are sport activities, like skiing etc, but also in other areas this is usually observed: reading, caring for animals etc.). The performance state during such an activity without stimulus usually is called ‘flow’(-learning/-performing) (e.g. Csikszentmihalyi 1990).

Figure 1. The enhanced cognitive model of motivation (according to Heckhausen & Rheinberg 1980); for explanation see text.

The state of ‘flow’(-learning) is the highest motivational state of any performance (acting/learning), because in this state the person performs without care for time etc. (it should be added here, that this can be observed in school-environments, too: e.g. during very interesting – and adequate – tasks, see below). In the next level, the expectation-level, the process of internalized analysis of a person is described: weighting and judging the possible benefits of the steps during a process of acting or learning is displayed by three expectation-steps (a result from the situation itself, a result from the action of the person and a expectation of the consequences; see Fig. 1). This four emphasised words leads to the episode-structure level. This episode sequences contains four steps, respectively four questions (Fig. 1). It is important for successful acting or learning processes to answer the question in a correct way that the episode-flow can be move on from situation to consequence, otherwise (one of) the four drop-outs occurs during the process: 1. acting/learning is redundant/waste, because the result is determined by the situation, 2. acting/learning seems to be nugatory, because there is no chance to influence it, 3. there is no certain result and 4. the consequences are irrelevant (to me). In all these cases a person will ‘drop-out’ of the process due to ‘wrong’-answers in the episode-structure. This model was proofed in school-environments, respectively during a preparation phase of a test (Heckhausen 1989). Students who do not pass all of the four answers (steps) successfully do not prepare for tasks (respectively the forthcoming test). Hence, this is also one possible explanation for loosing successively self-concept (-confidence) and disappear from coping with the tasks (of a specific area).

**Interests and their impact in science education**

Not only motivation, but also interests have a great impact in the teaching (and the learning) process. Krapp (2007) wrote about the person-object theory of interest (POI) „The empirical findings show that learning motivation based on interest tend to have many positive effects on the process and the results of learning.“ (p.7).
The initial development of the theory and the model was done in the 1970th and based on the work of several others (Schiefele, Krapp, Prenzel, Heiland, Kasten) (Krapp 2007, p. 7). The model is not only an attempt to develop a theory “which was explicitly oriented to the demands of educational practice”, Krapp furthermore underline the POI was developed “In accordance with the ideas of Lewin (1936), Nuttin (1984), Deci & Ryan (1985, 1991, 2002), Renninger (1992) and many others” (p. 7 and 8). Therefore, another typical interpretation of the interest construct is presented (Fig. 2a) (Krapp et al. 1992). This relates the person and the interestingness of the context together but failed to develop individual interest from situational interest (because the two aspects are grouped in one form; Fig. 2a, right). The development from situational interest to individual interest (as a deeper and more stable construct) is clearly shown in Fig. 2b, but this specific interest model failed in showing the characteristics (individual interest as a deposition) on one side and the interestingness of an object (as a characteristic) on the other side.

It is quite obvious that a specific motivation and the interest are often very strong related with content and furthermore – or particularly – with content presentation. Content presentation depends on media, in other words ‘media’ plays an important role in the context of motivation and interests. It should be remarked, that in biological education the phrase media includes animals, too. In this context it is meaningful that observation, ‘research’ and further work with living animals is one of the most demanded activities amongst students: in a study amongst 655 Slovakian students (o age = 13 years) Prokop et al. (2007) found that “One of the most striking results of this [attitude or interest KK] dimension is that, most of the students (83%) enjoy working with living organisms during lessons.” (p. 290). Thus, from several points of view the use of animals can be a promoter of learning processes.
Animals in biological education and the ‘explore-compare-square’

The main aims of using animals in biological education – as an excerpt from several handbooks – can be described as getting in contact with reality, multi-sensory learning, care for animals and further on more scientific approaches, e.g. observing, analysing, doing experiments (c.f. Eschenhagen et al. 2006). Amongst several reasons the “natural world contact” might play an outstanding role (Tunnicliffe & Ueckert 2007). In addition to these very global aspects especially within schools there is a large number of applications that includes beside just “looking” and “touching” special scientific approaches (e.g. Klingenberg 2007a). This will be discussed later in chapter 3; at first we take a closer look at the field of research on living animals in biological education.

**Animals in biological education**

The use of animals in (biological) education has been a field of discussions since Comenius’ theorem “Lessons should begin with consideration of the real thing, instead of descriptions with words, after the thing has been shown, the teaching should follow to explain it” (Great Didactics). Nevertheless, after ‘crisis’ of educational research with animals in the 1980th due to a transition of behavioural science and methodological problems (Klingenberg, 2007a), the need for including animals in teaching can be found in a great variety of newer studies: e.g. from the side of teachers view (e.g. Adkins & Lock 1994, Lock 1996, Zasloff et al. 1999, Klingenberg 2007b) and also from the students view (e.g. Tamir & Sheurr 1997, Klingenberg 2008, Meyer et al. 2009, Klingenberg submitted).

Although some older approaches might have methodological shortcomings, too (e.g. Tamir & Sheurr 1997: A study which reported “…high interest in animal” but uses not a usual pre-post design), other recent research clearly reveal that not only emotional facets are influenced in a positive way by using living animals in science education (Klingenberg 2008, Meyer et al. 2009). Also cognitive outcome alters significant (refer to above discussed models of motivation and interest) which is shown by Klingenberg (2009b, c). This study is carried out in a strictly new designed pre-post test setting. The students of the two interventions groups were both taught in identical settings (group work) with identical contend but only with different media (one group with living animals, the other by short educational video sequences of animal movements, behaviour etc.). The animal-group performed in a significant better way, which can be easily explained by using above models of motivation and interest (Klingenberg submitted).

**Animals and the ‘explore-compare-square’**

Anyway, these models tell us very little for setting up structured learning environments for exploring nature. Thus, for the intervention studies in biological education and for the tasks during the workshop at the ESERA-Conference in Istanbul a model for gradual exploring nature is used (‘explore-compare-square’; Fig. 3). This is a useful theoretical background of guided interaction and learning (Klingenberg 2004). It is based on an earlier model which lacked of some methodological aspects (e.g. comparing) (Klautke 1997). The main approach is to identify and classify forms of exploring nature. Four (almost universal) different forms can be categorized; they represent different levels in their complexity of approaching nature (under the perspective of scientific exploration).

At first, to look at an animal or a specific phenomenon can be described as the primary step of exploring (Fig. 3). Usually this is base on the (relatively) naïve pre-concepts (of the students). This step is not inevitable a complete systematic approach to animals or phenomena, but will be proceeded by the more structured observation of a process (e.g. movements). Developing a deeper understanding of the specific structure will be done by analysing (which can be as well done by models, e.g. of inner structure of animals etc.). Analysing a process or the systematic observation of a specific structure leads to the experimental approach, the most complex “question to nature”. All these explorations are especially in biology based on the comparison, e.g. to already known animals, phenomena etc.
Meaning making with living animals and obstacles of animal investigations

**Principles of meaning making**

Before starting scientific observations and investigations with animals (‘meaning making’), the students should have the opportunity to get in direct contact with the animals at first in a usually emotional and pre-scientific way. This is not a waste of time, because the none-discussed attitudes would otherwise be present immanently during the scientific part of lessons, which can impair the learning process. Children usually have an ‘open-minded’ attitude towards animals: “But it is not only about domestic animals. Insects, snails, frogs, birds, animals from farms – children are usually interested and fond of animals [...]” (Gebhard 2001, p. 122).

Meaning making in the sense of developing a deeper understanding of nature can be basically seen as the ability to ask “good questions”. This phrase means: Biology cannot give answers to questions regarding “feeling” or “thinking” of animals -although this might be interesting for students-, because this is beyond the methodological approach of science. Scientific instruction cannot replace everyday-experience with animals, which is a significant positive influence in building up elaborated concepts of animals (e.g. Hatano & Inagaki 1997, Prokop et al. 2008).

Many critical comments on teaching (behaviour) with living animals focus on the variability (Klingenberg 2007b). This is remarkable, because teaching the natural range of behaviour (or lesser complex: “response” to a stimulus) should be seen as a chance and not as a limitation. Respectively, this phenomenon leads to an important “tool” of science: variability is a practical approach and a paradigmatically reasoning of statistics (mean, SD ...). Additionally, unusual “errors” supports talking about dealing with errors and artefacts – which is a basic concept of measuring and handling data, too (Hug & McNeil 2008). Anyway, all of the dimensions of animal investigations promote cognitive and emotional learning (Klingenberg 2008).
Obstacles of animal investigations in schools

Currently, some aspects seemed to be obstacles for several applications in schools; these have been limitations (or rather obstructions) in every time, but today they seemed to step forth: e.g. strict time schedules, activities of ‘animal rights’ organisation and legal authority aspects as well as some general problems within teaching animal behaviour. Regarding limitations of organisational and time schedule questions, this will be not discussed deepened here, while most of these arguments are already critically discussed by Tranter (2004). Several problems might occur from defective equipment, unsafe or inadequate rooms; these problems are as well not an issue here to discuss, because they are easy to solve. For solving such obstacles, the main influence comes from school and attitude factors as well as influences of advice and support and personal engagement (Adkins and Lock 1994, Lock 1996).

Some ‘newer’ restrictions caused by ‘animal rights’ activists and legal authority issues might cause ‘unsafely’ situations for teachers (e.g. Klingenberg 2007a, c). Indeed, in the last decades a greater awareness of the handling of animals (especially in ‘lab’-situations) can be observed. In several countries rather quite restrict codes (or laws) regulate very strict how to handle animals in education (e.g. Australian Government 2004). Also in Europe, several ‘newer’ statutes (rather amendments of already existing regulations) seemed to exclude animals from teaching (e.g. Animals Protection Acts, Nature Protection Acts). Especially in Germany the situation is analysed by the author (Klingenberg 2009a). As an over all result, most limitations are caused by misunderstanding and misinterpretation of legal authority regulations. This is not a problem caused by teachers but – or especially – by Science Educationalist (wrong interpretation, see Klingenberg 2009a, p. 35) and wrong or confusing advice from school authority (Klingenberg 2009a, p. 34). As well some mistakes or disagreements can be found in statutes (e.g. regarding nature/animal protection, but more often misinterpretation of national laws). The European habitat-directive (92/43/EWG; May, 21st 1992) in general rules in Art. 22 c, that the countries take educational action for implementing the goals of the directive. This means, that curricula and especially biological education should cover at least some of the issues regarding the fauna. It should be emphasized here, that supporting knowledge acquiring and attitude changing (towards a positive mentality), is more effective with animals than with other methods (Düker & Tausch 1957, Tamir & Shcurr 1997, Prokop et al. 2008, Klingenberg 2008, Klingenberg submitted).

At last a still not well elaborated aspect (also of legal authority issues) is an (partly) increasing -but inadequate- perception: The use of animals in science education equals NOT some kind of a potential ‘cruel’ or damaging situation (e.g. like some experimentation in research). Neither the educational situation is ‘research’ itself (because the ‘expected’ result should be almost clear to the teacher), nor the use of animals in science education is harmful. Educational environments ensure (in nearly all cases) non-destructive investigations (c.f. Ogilvie & Stinson 1992) (‘destructive’ environments might be limited to very small animals, e.g. research of protozoa etc.). Furthermore, the main aim of teachers is to foster a positive attitude towards ‘larger’ animals (Lock 1996, Klingenberg 2007b).

Practical examples and guiding material

This chapter will give an impression from the practical part of the workshop held at the ESERA-Conference Sept. 01st 2009. A general introduction to this chapter will be the question: ‘Why working with living animals?’ This is probably almost answered in chapter 2.1.2 with the quotation “One of the most striking results of this [attitude KK] dimension is that, most of the students (83%) enjoy working with living organisms during lessons.” (Prokop et al 2007, p. 290). But it is not only the ‘enjoyment’, important goals like knowledge building and attitude changes can be promoted by living animals (see above).
Practical examples

The following survey of the examples is only a short description of chosen applications. The focus is (due to the limited time of the workshop) on ‘short time’ applications. This is a frequent use in school science education: even teachers who integrate animals frequently and kept several species, set up more short time investigation during the educational settings with living animals (e.g. Klingenberg 2007b). In addition, only invertebrates can be transported quite easily (also by plane) and due to the reported misconceptions particularly about invertebrates (Prokop et al. 2008, 446 ff.), the following examples only refer to this group. The examples of the workshop are described, following the above discussed principles (‘explore-compare-square’). The application ranges from primary school to middle and high school, representing a cross-section through topics of instructional settings and acquiring knowledge (mainly in group-working environments). All tasks are developed according to the educational standards (KMK 2004; Bildungsstandards Biologie) and the curricular standards of Lower Saxony (Lower Saxony Ministry of Education 2004; Curriculare Vorgaben).

a) “Earthworms” (Eisenia fetida or similar species): At first a very open environment gives the opportunity for first contact and afterwards detailed observation (from looking at to observing, see Fig. 3). The observation task offers surprising results, even to this -usually- well-known organism, e.g. did you know/show in an easy way: is there a head/tail? And if: where is the head, where is the tail? Does the worm look same on back and front side? Listen to the movement on paper etc. With experimental tasks (reaction norm to different salt-solutions) a higher challenge-stage can be realised (as well in the primary school level).

b) Starting at the experimental level, a very easy and impressive example can be set up with the rough sow bug Porcellio scaber (or similar species): the reaction to light-exposure. For this experiment only simple Petri-dishes and a piece of black (or dark) pasteboard is necessary. A small number of sow bugs are kept in a complete covered lab-dish; the pasteboard-coverage should be removable, preferably changing to one or the other side. The sow bugs will always move fast to the darker side of the Petri-dishes and show strict light-avoiding reaction.

c) Amongst the most attractive invertebrates of ponds in Europe, the dragonfly nymph of the Southern Hawker (Aeshna cyanea) can be noted; even if this dragonfly is common, permission for observation is necessary in most countries. With its scoop-like lip (labium), the nymph captures food, if it moves in front of it. Starved nymph (for 1-2 days) will show several prey-catching reactions on smaller, slow moved things (e.g. a toothpick). The stimulus-reaction concept and Schlüsselreize (‘key’-stimuli) can be shown with a small number of simple experiments. Additionally, while moving in plants or on ground for faster movements water is pressed out of the rectum. Than the nymph moves like a rocket propulsion, this can be easily made visible. Students can discuss this phenomena and revise their (previous reasoned) presumptions, typically wrong speculation of air pressed out of the body or similarly (this is easy to demonstrate with a pipette model-experiment).

d) The adult backswimmer (Notonecta sp.) can be chosen to demonstrate the adaptation to two worlds (water, air) as well as for foraging and movement experiments, too (see Fig. 4). For testing the attractions of the prey-object (mock-up/dummies or real objects, e.g. liver, mosquito nymph) a simple test-setting is possible for indoor or outdoor use, which demonstrated the ability of stimulus reception. Before (and during) these observations the previous questions (e.g. adaptations to water: legs, colouring) can be discussed deeper.

e) Genetic approaches usually are abstract, because of missing examples for schools (except Drosophila ssp.). Nevertheless, the common snail Cepaea nemoralis and C. hortensis are well known examples of polymorphisms. Within a practical classification of colouring and band-pattern an application for out-door Biology (e.g. in schools-garden) and an example of modern biodiversity-education can be demonstrated. This is preferable done in a divers habitat structure (if possible schools-garden or similar) with woods, meadow and further types of grass-land. Colour and band-pattern are typical distributed in the different habitat types (banded and yellow individuals in grass-land, unbanded and brownish individuals in woods). This can also be demonstrated (if no adequate habitat is reachable) by the shells only in a model experiment.
Guiding material

For every organism a special worksheet was designed to guide the ‘researcher’ through the steps of asking good questions (looking, observing, analyzing, doing experiments; see Fig. 4). These ‘guiding material’ should not be seen as an application for preventing own questions (the material should be an aid, not a substitute of it). Nevertheless, guiding students from naïve pre-concepts to scientific implications, it is necessary to ask (good) questions and (try to) solve this by specific tasks (e.g. see Fig. 4). For a more open (e.g. more dialogic) teaching process a discussion (and election) of own questions is a possible option before starting the activities based on the worksheets. It is necessary to limit the questions of the students to answerable questions according to the restriction examples in Chapter 2.3.1 (e.g. feelings of animals).

Figure 4. An example of a work-sheet (for High School use) and the basic structure of it (see text fields).

Identical areas simplify the work-flow and guide the process step by step from easier to difficult tasks (Fig. 4). Worksheets contain usually five to six different tasks (all worksheets will be available at http://www.ifdn.tu-bs.de/didaktikbio/mitarbeiter/klingenberg/esera2009_animalworkshop.zip; further information and media support, e.g. ‘how-to-handle’ videos can be found there as well: sow-bug clip http://www.ifdn.tu-bs.de/didaktikbio/mitarbeiter/klingenberg/assel.divx). During the student-centered work the ‘explore-compare-square’ guides the exploring process for every ‘researcher’. This tool is a metacognitive help, thus not only the practical work will be
done (as often in practical environments, c.f. Abrahams & Millar 2008): also a critical reflection of what is done at the moment and for which particular purpose will be much more explicit to the students.

Reflections, Conclusions and Implications

The workshop was highly frequented. Several of the here discussed issues of theoretical and practical aspects of animal use in science education were as well main points during work-flow and discussion (e.g. the use of worksheets, instructional proceeding, metacognitive tasks, animal handling). As one of the main reflection it can be concluded, that practical work – especially well structured and with metacognitive elements – provides a powerful environment for building knowledge (and helps to change attitudes in more than one dimension). From my personal point of view it should be remarked that it was, after all, a quite challenging task (of course not the paperwork or the presentation of selected models, rather bringing in animals and equipment etc.). But it was a great confirmation to have an interested and engaged auditorium – what might be a similar motivation for teachers, too.

Practical work with living animals is faced with several doubts or reservations: e.g. time consuming preparation, inadequate effort/effect relation etc. (see above). However, regarding several newer research and the implications of the here presented theoretical basis together with its practical application, this seems to be one of the places “Where Learning Happens”: this is what Johnston et al. (2007) have focused on with the “Calling for a Focus on Where Learning Happens” which is the title of their reply to the critique of CCT and further theories of learning by Abd-el-Khalick & Akerson (2004, 2007). Living animals catch the focus of our attention and promote learning processes - is this a really new perception? Probably not: “As a result of my long time experience, nothing catches children’s attention as early (and as much) as – animals” (Salzmann, Amiesenbüchlein, p. 31). Salzmann, who was a famous pedagogical reformer and school founder, integrates animals in his teaching on every opportunity. He lived 1744-1811...

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LEARNING IN THE LABORATORY: 
AN INTERACTIONAL, FACTUAL AND CONCEPTUAL EXPERIENCE

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Abstract

When the teacher acts in a particular way, how does the student probably experience his act? What is the nature of these experiences and how teachers may influence them? Our starting point was a three-dimensional model (subject, object, project) defining three domains of experience: the interactional, perceptual domain, the conceptual, mental domain and the factual, concrete domain. We adapted this theoretical framework to the context of learning in the laboratory. It is assumed that all three domains are present in any learning experience but that some laboratory sessions may be dominated by one or the other domain. We present the consequences of this model for the design of laboratory sessions. Three types of laboratory situations are presented that lead to different natures of student experience and that are possibly connected to different learning outcomes. Using the framework, we derive the problems involved in using only one type of laboratory. Finally, we argue that if several types of laboratory calling on different domains of human experience are proposed, laboratory work becomes a privileged activity in which these domains can be used for learning purposes.

Background and questions

Hofstein and Luneta (2003) define science laboratory activities as “learning experiences in which students interact with materials and/or with models to observe and understand the natural world”. Students learn by performing concrete activities, by comparing experimental data to a model, and/or by designing an investigation. The second generation of cognitive science (Klein, 2006; Prain & Tytler, 2007) now associates conceptual knowledge for learners with more sensitive, perceptual and concrete experiences. The questions raised are thus the ways in which perceptual and concrete approaches can be used in the design of laboratory work, and the reasons for which it is important that they be taken into account. We propose a model for the analysis and design of laboratory work that focuses on the nature of student experiences induced by the teacher. We will hereafter use the term ‘labwork’ to refer to laboratory work (Tiberghien et al., 2001).

Many authors insist upon the uniqueness of the learning experience in the laboratory. White (1996) claims that it is the quality of the experiences that students have there that is critical. What is unique to labwork? In some situations, labwork is the only means (or at least a privileged means) by which to teach manual dexterity - including fine movements, precision and care - and the acquisition of specific techniques. The lab is also a place where students can be taught how to design and conduct an investigation in order to solve a scientific problem (Hofstein & Lunetta, 2003; White, 1996). For some researchers and teachers, the added value of labwork is that it enhances motivation, and stimulates excitement by providing unusual objects and events - a contrast with the usual learning
experience of sitting still and listening or doing exercises. Moreover, the laboratory is said (Hofstein & Lunetta, 2003; White, 1996) to be a place where personal experience can be linked to a scientific way of reflecting on that experience (using scientific representations of the world such as models). The students’ personal experiences are either their direct observations of a phenomenon through hands-on manipulation or their recollection of past experiences (e.g. in a Mechanics course a teacher could ask students: “What did you feel when the elevator started or stopped?”). Understanding student’s personal experience more effectively is essential in order to create a learning situation that encourages and challenges students to develop experimentally-based inquiry skills. Laboratory work involves thinking, feeling and doing, and the lab is a hub of interactions between these three aspects. To elaborate on this, we will first review the literature on discussions and evidence as to how feeling and doing provoke learning in the laboratory.

This paper addresses the following questions: What is the nature (the different domains) of students’ experience during a laboratory session? What are the teachers’ acts that lead to different natures of student experience? In the following parts of this paper, we will firstly propose a framework derived from a theory (with a brief introduction to that theory), which suggests an answer to our first question. We will then present empirical studies to answer to our second question. These studies have enabled us to build tools from the proposed framework and to illustrate the concepts introduced by means of concrete examples. Finally, the discussion raises the consequences for the design of labwork.

Literature review

A range of different tools and frameworks have been proposed to categorize and study different learning domains, and the goal here is merely to provide a rapid overview. One of the earliest and most widely used systems is the Bloom taxonomy, with its three learning domains: the cognitive, the affective and the psychomotor. Bloom worked on the cognitive domain (1956), while the affective domain was later developed by Krathworl et al. (1964). Simpson and Harrow ultimately provided a classification of the third domain, the psychomotor domain: see e.g. Bergendahl (2004), or Forehand (2005) for a historical review.

There are a number of definitions concerning the affective domain, which accordingly comprises several sets of variables, see e.g. Gungor et al. (2007). A wide range of affective factors have been studied, including interest, motivations, feelings, emotions, values, or attitude toward science. In a review on learning and teaching in the affective domain, Miller (2005) adopts the view that this domain covers attitudes, motivations and values. She argues that there is a need for theory, and proposes several frameworks from psychology to educational sciences. Nieswandt (2007) considers interest, self-concept (perceptions and belief about oneself based on past experiences) and attitudes as the main affect components, in a study of the relationship between affective and cognitive variables in high school students taking chemistry for the first time. Several authors in the literature of science education acknowledge the fact that learning is influenced by affective factors (see e.g. the special issue of the Journal of introduced by Alsop and Watts 2003). However, there are few empirical studies on how it may do so in this field (Hofstein & Lunetta, 2003), although many authors stress that the laboratory provides a complex perceptual experience (e.g. Gooding, 1992). Alsop and Watts (2000) explore the issue of students’ feelings about a topic (in this case, radioactivity, which aroused mostly negative feelings) to determine whether or not these feelings influenced their approach to learning. In their view, the aim underlying the introduction of non-purely cognitive learning is to depart from impersonal and “antisepsic” science (Alsop & Watts, 2000). In a study of relationships between achievement and affective characteristics in physics freshmen, Gungor et al (2007) put forward two arguments for the importance of affective factors for learning. The first of these is the impact of affective factors on achievement, and the second is the fact that affective factors are more important for life in society than cognitive factors and should be given priority. The latter is related to the loss of interest in science: “students think that science is not related to them” (Gungor et al., 2007).
Prain (2007) shows that when a perceptual approach is used when learning science, students make sense of phenomena by drawing on perceptual links. He considers that a perceptual approach increases the construction of the individual path to meaning. For Coquidé (2000) the connection with reality has at least two effects. Firstly, effective and authentic practices allow the discovery of techniques and of their constraints, and contribute to a choice of positive vocational guidance. Secondly, they lead the learners to be aware of the need to manage the materiality of sciences, an essential element of any scientific or technical culture. As stated by Gooding (1992), the dominance of head over hand leads to an intellectual view of science, and the way in which kinesthetic activities provoke learning in the laboratory is therefore still unclear, and challenged. Several authors discuss the relationship between doing and learning in the laboratory, for instance between practical actions and reflection on scientific theories behind these actions. This relationship can make things more concrete by illustrating abstract phenomena and concepts and by making the facts visible. Millar (2004) defines practical work as: any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials. Millar (2004) wants to promote “knowledge in action”, and a more explicit, reflexive and declarative knowledge. He claims (Millar, 2004 p.2) that “as Piaget argued, it is by acting on the world that our ideas about it are formed and develop. Students need to have experiences of acting on the world, in the light of a theory or model, and seeing the outcomes”.

It is not easy to separate thinking from doing or feeling and study their impact on learning. Because these three domains are always present in any learning experience and particularly important in those that take place in the laboratory, there is a need to define them in a single framework. However, few authors have worked towards establishing consistency between these three domains, particularly in research in science teaching.

**Proposed theoretical framework**

We would first like to state explicitly our position on both learning and knowledge. Our position on learning comes from Dewey (1938/1968), who considers that research on learning needs a theory of experience. Furthermore, our position on knowledge of the natural world is summarized by Bachelard (1934/1985, p. 15), who expresses the notion of a three-dimensional reality as follows: the subject cannot reflect on the object without considering the project. Let us take an example to illustrate the notion of a project: I (subject) use a pen (object) to write here and now (project), but I can have many other projects for this pen, for instance using it later to dial a number on a phone. This experience of interaction with an object, the pen, is fully described only through the project. From Bachelard’s point of view, reality is not reduced to an interaction between subject (a scientist or a community) and object (devices, materials and phenomena of science). There is a third dimension, which is the project that allows considering the spatial and temporal deployment of the reality under consideration.

The aim of our second research question was to understand the student’s experiences as organized by a teacher in the laboratory, that is, to infer the students’ learning experiences from what the teacher does and asks them to do. To analyze teachers’ discourse and writings, we used a framework that is coherent with the two positions mentioned above. We found a way to elaborate on Bachelard’s view of reality by using the Theory of Sense and Human Coherences (Nifle, 1986). This theory is presented in a French philosophical essay, Nifle (1986), and used mostly in non academic situations (but see a recent study on teaching modeling, Ney, 2006). Sense is a specific view of the world, a specific logic, held by an individual, a community or an institution, according to this theory. This view reveals itself in attitudes, behaviors and representation, giving an orientation and a coherence between thought and action. The theory is based on three assumptions: (1) reality (what one can consider, apprehend) is always a life experience (2) reality is an instance, a product, of a shared Sense, and (3) reality is described by three variables or dimensions, subject–object–project (figure 1).
From these assumptions, Nifle (1986), and see also (Ney, 2006), introduces a three-dimensional structure called a coherenciel and formed by
- the subject dimension (pointing upwards in figure 1) is the expression of an intention, the desire to consider an object or a phenomenon. This intention can have many forms: desire, motivation, tendency, aspiration. Indeed, any reality is that of a particular person (or community or institution)
- the object dimension (pointing downwards, left) is what can be distinguished from its context and also from ourselves by the attention that we pay to it. It can include things, models, people and other resources.
- the project dimension (pointing downwards, right) is the vector product of the other two dimensions and represents reality deployed and ordered in time and space. Reality continuously evolves through the interaction of subject and object.

Pairs of dimensions form planes (see figure 1) that will subsequently be referred to as domains of experience: interactional, factual and conceptual (Nifle, 1986). The plane formed by the object and subject dimensions is the domain of affect and interactions: interactions between subject and objects. It is called the interactional and perceptual domain of experience. The plane formed by the project and subject dimensions is the domain of concepts and representations, and is called the conceptual and mental domain of experience. The plane formed by the project and object dimensions is the domain of actions and facts, called the factual and concrete domain of experience.

We will now answer our first question: What is the nature (the different domains) of students’ experience during a laboratory session? A teacher who organizes a predominantly interactional experience may ask students to familiarize themselves with the apparatus, to contextualize the problems involved, to situate themselves (who does what, how do I feel about this), and to get a “feel” for a phenomenon. These are sources of perceptual and interactional experiences. This plane (the interactional domain) is orthogonal to the project dimension (figure 1), since it is not necessary for students to plan actions and organize tasks according to an objective. Next, with respect to the conceptual domain, students are asked to construct their own view and their own ideas, either in order to anticipate the analysis before carrying out an experiment, or to represent their results; they may spend most of the laboratory time debating on models and concepts. These are mostly mental or conceptual experiences. This plane (the conceptual domain) is orthogonal to the object dimension (figure 1), which reflects the fact that students do not
need to interact directly with all the practical components of the experiment (roles of teacher and students, timing, apparatus, labsheet available, material constraints); they merely need to have an idea or image of these components. Finally, focusing on the factual domain, students are asked to observe phenomena, to perform the experiments and execute a protocol. They have to ascertain scientific facts, and experience that things happen. This is what we mean by factual or concrete experiences. This plane (the factual domain) is orthogonal to the subject dimension (figure 1), and indeed students do not need to appropriate the scientific issue under consideration in the laboratory session in order to execute a protocol or make observations. They can be guided in their observations and experiments. Although we have just considered them two by two (i.e. each two-dimensional plane), the three dimensions are to be found in every reality, or human experience. A human experience such as that of the student in a laboratory session can thus be deployed on this three-dimensional structure. Nevertheless, the teacher may choose not to consider all three and to emphasize one or two dimensions for learning, and thus focus on a single plane or domain of experience.

To get a feel for the three domains of learning experience as defined in this framework, let us take an example: imagine that you are a student in a laboratory session entitled “the intern anatomy of a frog”. It can be a mostly interactional or perceptual experience for you if you are asked to touch and feel the frog, open it and freely draw what you see. You will probably remember your aversion to or curiosity for the experience. It does not necessitate any experimental planning: the interactional domain can be seen as the absence of the project dimension (figure 1). By contrast, it may be a factual, concrete experience if you are asked to follow dissection instructions. You will remember things such as the fact that you need gloves for this dissection, that forceps are useful, that frogs have no necks, that males are smaller than females, etc. Moreover, simply following the “recipe” does not require that you understand why: the factual domain can be seen as the absence of the subject dimension (figure 1). Finally, it can be a mostly conceptual or mental experience for you, if you are provided with a diagram of an open frog, a typical biological representation. You are told that the aim of the dissection session is really to identify and label each organ in the diagram. It is not absolutely necessary to dissect the frog, and you memorize the image of a diagrammatic frog rather than the body of the frog: the conceptual domain can be seen as the absence of the object dimension. In fact, in any of these lab sessions, you have a three-dimensional learning experience combining (figure 1) the factual, interactional and conceptual domains, as it is not possible to separate one from the other. However, our point is that each of these imaginary lab sessions would be dominated by one domain or another, depending on the instructions given by the teacher.

Other frameworks emphasize similar domains of experience. As we saw in the previous section, a group of researchers led by B. Bloom identified three domains of educational activities: cognitive (mental skills), affective (feelings or emotional areas) and psychomotor (manual or physical skills). By elaborating on this framework, Hostorm and Ottander (2005) used these three domains to analyze teachers’ discourses on the aims of their labwork. Using another framework, Gooding (1992), when studying the way in which scientists construct their production, referred to the interaction of concepts, percepts and objects (the latter can be understood as perceived events or objects, Tiberghien et al., 2001), that is similar to the domains presented above. These works differ from ours in that here we present an integrated view of the three domains (figure 1) that reveals them in a new light. We define a domain as a plane determined by only two of three dimensions.

**Empirical studies**

We conducted two empirical studies. The aim was double: one the one hand, to illustrate how to use the proposed framework, and on the other to build tools to analyze labwork according to the three learning domains. In short, the data and the focus of their analysis are the following: (Study 1) 8 semi-structured interviews of teachers (practices in a lab session,) and (Study 2) content analysis of 15 labsheets (tasks given to the students). Both studies enabled us to answer our second question, since both provided us with teachers’ acts in the form of discourse on practices (study 1) and written instructions (study 2). These teachers’ acts were analyzed in terms of the domain of
the students’ experience. The question asked was: When the teacher acts in a particular way what does the student probably experience? Is this experience mostly conceptual, factual or interactional?

In study 1, after selection of the eight courses, we interviewed the teacher of each course and first agree on a particular laboratory session to be discussed. Such sessions usually lasted four hours. The interview, using the ‘stand-in’ technique (Clot, 2001), introduced a setting in which the interviewee (here a teacher) was told to imagine that the interviewer (here a researcher) was going to stand in for him or her the next day in the lab. The teacher was thus interviewed about the reality of the laboratory session for him/herself and the reality of the laboratory for the student as seen by the teacher. The interview was semi-structured, and included ad hoc questions that made it possible to determine what students had to do (according to the labsheet), what they did, the time allocated to the different parts of the lab, the difficulties encountered by the students and how the teacher might help them. In study 2, the content of 15 labsheets was analyzed. The labsheet was chosen as material for analysis because it is the students’ first contact with the labwork and because it shows how they will engage in the lab activity (assuming that the teacher does not intervene excessively from the beginning). Tiberghien et al. (2001) underline that written instruction materials are the ideal medium for studying regular practices as they embody the decisions and perspectives that shape that practice. There can, of course, be considerable variation in the way the labsheet is used by the teacher, but we did not have access to that information in this particular study. We used materials from another study in the same research project, namely the CoPEX project that explores learning by designing an experimental procedure, (Girault et al. in preparation, Marzin, d’Ham, & Sanchez, 2007 ; Wajeman, Girault, d’Ham, Ney, & Sanchez, 2005). We used their selection of labsheets from the two first years at university, i.e. five in physics, five in biology and five in chemistry.

In both studies, the question asked is whether the labwork engages the students in a learning experience that is predominantly interactional, factual or conceptual, in cases where predominance can be identified. We used the coherenciel (figure 1) to categorize excerpts of teacher discourse (study 1) and paragraphs in labsheet (study 2). We ended up with a grid of analysis dividing each labwork into three parts: (1) the introduction, where students are given questions or tasks to engage them in the lab; (2) the central part, where they are given information on how to collect data and carry out experiments; and (3) the conclusion of the labwork, where they are given indications as to how to conclude (see table 1). One goal of our studies was to improve our tool to analyze current practices in labwork. Table 1 is the final version of this tool.

<table>
<thead>
<tr>
<th>Location</th>
<th>Interactional</th>
<th>Factual</th>
<th>Conceptual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>Compare with previous experience – Ask oneself questions – Explore</td>
<td>Characterize experimental apparatus – Make measurements – Ascertain facts</td>
<td>Elaborate a model – Verify a law or the domain of validity of a model – Define a concept – Build an image, a representation</td>
</tr>
<tr>
<td><strong>Experiment</strong></td>
<td>Familiarize oneself with scientific objects and phenomena – Tackle differences with common sense – A somewhat informal procedure. Example: a list of equipment is given and students are asked to examine it and maybe make drawings or list comments.</td>
<td>Operational protocol: series of actions, operations and parameter values. Example: the typical ‘recipe’ experimental procedure.</td>
<td>The time spent obtaining data is reduced – the experiment is a tool used for modeling purposes – the procedure is dominated by instructions on how to represent, process and interpret data. Example: a drawing, an equation or graphs that students are supposed to use to design their experimental procedure.</td>
</tr>
<tr>
<td><strong>Conclusion</strong></td>
<td>Derive new questions, new directions for exploration – Build personal perception of objects and phenomena</td>
<td>Give values – Compare with theoretical or expected values – Indications on how to present data</td>
<td>Reflect on validity of model – Reflect on presentation of results – Defend conclusions drawn from data</td>
</tr>
</tbody>
</table>

Table 1. Proposed grid of analysis.
The results of study 2 are presented in Table 2. It shows that, from beginning to end (i.e., the three parts), 7 labsheets were predominantly factual, that only one was conceptual (in physics) and none interactional. Furthermore, our results (Table 2) show that: the interactional domain is very seldom predominant in any of the three disciplines (4/45 parts in biology or physics labsheets) and the conceptual domain is rarely predominant (14/45 parts) elsewhere than in physics (10/14).

**Table 2. Results from the 15 labsheet analysis.**

<table>
<thead>
<tr>
<th>Scientific field</th>
<th>Introduction</th>
<th>Experiment</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal biology</td>
<td>F / P</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
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</table>

The labsheet analysis and the teachers’ interviews lead to new questions and assumptions. First, some lab sessions seem to be organized in such a way that the students’ experience is predominantly factual, interactional or conceptual. Our studies suggest two hypotheses: (1) the interactional domain is rarely predominant in any of the three disciplines and (2) the conceptual domain is rarely predominant elsewhere than in physics. It is to be noted that some lab sessions were not classified in the same domain from beginning to end, a session sometimes starting as factual and ending as conceptual, and another starting as interactional and ending as factual. At the level of a laboratory course, one may ask whether successive sessions should (depending on aims) go from a more interactional experience to a more factual one, to end with a conceptual part. We address this issue in the following section.

**Discussion and Implications**

The first question in this research concerned the nature of the learning experience that is organized by teachers in the laboratory. Our starting point was the three-dimensional structure of human experience based on the Theory of Sense and Human Coherences (Nifle, 1986) and our previous work (Ney, 2006). We then adapted this framework to the context of learning in the laboratory. This led us to characterize three domains of experience: interactional, conceptual and factual. It is assumed that all three domains are present in any learning experience but that some laboratory sessions may be dominated by one or the other domain. The second research question focused on teachers’ acts that lead to different types of experience in the laboratory. This question was first answered on the basis of eight interviews of teachers and 15 labsheet analysis. In summary, in these analyses we found typical features that could be attributed to each of the three domains of experience. These analyses allowed us to illustrate how to use the proposed framework, and to refine tools to analyze labwork according to the three learning domains.

Moreover, this work led to a proposition presented in this section. We define three types of laboratory that have different functions. One of these proposes interactional/perceptual experiences, another factual/concrete experiences and yet another conceptual/mental experiences. We indicate the features of each type of laboratory, and also the possible consequences of focusing only on a particular type of laboratory. This is to argue in favor of series of laboratory sessions that target different experiences and do not focus on one of them alone.
The “interactional laboratory”. We call an interactional laboratory a first type of session where students are typically asked to make comparisons and to ask themselves questions. They do so by exploration, by familiarizing themselves with apparatus, living things (in biology) or phenomena. They can use their senses to ascertain differences between their beliefs from past experiences and what they observe. The method they work with are not formal, and their actions are based mainly on their feelings and intuitions about the phenomena. The teacher uses this type of laboratory to enable students build an initial representation of the phenomena, and ask questions, which will later be elaborated into scientific questions. This laboratory makes it possible to build a common experiential ground shared by all the students in a class. The role of the teacher is to encourage students to make comparisons, to ask them questions, to introduce doubts, and to help them to formulate their own questions. The problem when focusing exclusively on this type of laboratory is the absence of the project dimension (figure 1). Students could have an image of science that lacks organization into scientific methods and procedures and clear objectives.

The “factual laboratory”. This second type of laboratory is defined as follows: students make measurements, ascertain scientific facts; they follow experimental procedures that appear as a series of operations. Their confrontation with phenomena is guided. They note that certain things happen under certain circumstances. The teacher guides them to make observations and perform manipulations. He/she helps them to relate facts, to identify sources of measurement error, and to see causalities (when I do that, I get this). Some attention is given to bibliography, since students should know other experimental results. They learn about known procedures and methods that work. The problem when focusing exclusively on this type of laboratory is the absence of the subject dimension (figure 1); that is, students might not appropriate the question and might not relate the scientific questions to the procedure itself (Why do I proceed this way? How should I answer this type of question?).

The “conceptual laboratory”. In this laboratory, students elaborate a model, verify a law, test the usefulness of a law or a rule. They may elaborate a concept or a representation. The experimental procedure plays a minor role in the session. It is a tool that serves the conceptual work or the modeling. The experiment may even be simply alluded to, with students working directly on data. The data analysis plays a larger part in the session. The experimental procedure comprises both theoretical elements (equations, diagrams, etc) and operations, and students are asked to switch back and forth from theory to experimental facts. They are asked to build a theoretical or conceptual image. The problem when focusing exclusively on this type of laboratory is the absence of the object dimension (figure 1): students might not relate the resulting models to material conditions and constraints.

To conclude, we have emphasized the problems involved in using only one type of laboratory. Hence, we propose to use all three types and to integrate the three into a series of laboratory sessions. For instance, especially for students who are not yet expert experimenters, a series could be designed as follows:
- an interactional laboratory session to get a feel for phenomena, to discover, and to explore,
- a factual laboratory session to make measurements, to ascertain facts, and to learn about known procedures,
- a conceptual laboratory session to conceptualize, to model, and to construct representations.

Interestingly, in a work based on several definitions of the term “experience”, Coquidé (2003) proposed three similar modes of teaching in the laboratory. She defines an experience as either “experientiation”, an “experiment” or a “validation-experience” leading to three corresponding modes of teaching. The difference here is that we focus on the domains of experience and characterize these domains in terms of a theoretical framework. By organizing several types of laboratory calling on different domains of experience, each with its own logic and its own demands, each requiring its specific form of teacher guidance, the teacher can tackle different learning issues. If contrasting situations are proposed, laboratory work becomes a privileged activity in which the different domains of human experience can be used for learning purposes. An open question remains for future work: what is the impact of the different types of laboratory on learning?
References


Teaching and Learning Deterministic Chaos: An Empirical Study on Pre-Service Teachers

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Abstract

The study presented here investigates the possibility of teach and learn the limited predictability of deterministic chaotic systems to pre-service teachers. The teaching sequence developed used a commercial chaotic pendulum interconnected with a data acquisition interface. Eighteen pre-service teachers of primary education took part in the investigation. In order to collect the data, experimental interviews, a so-called "teaching experiment", were used. The analysis of the data shows that it is possible to guide teachers-students to the idea of the limited predictability of deterministic chaotic systems. Conceptions about the connection of determinism and predictability as well as of chance and non-predictability cause some difficulties.

Introduction

Non-linear systems have become a major area of research in both science and in domains outside science. An important class of systems described by non-linear models is that of deterministic chaotic systems (Schuster 1989). Deterministic chaotic systems show in their evolution an irregular complex behaviour, which is however generated by fixed deterministic rules. This becomes apparent after a suitable representation of the behaviour in the so-called phase space (chaotic attractors). In principle, the future is completely determined by the past. However, in practice, due to their 'sensitivity' to small changes in the starting conditions and small disturbances when the process is running, the behaviour, even though predictable in short terms, is unpredictable in long terms (limited predictability).

Analyzed from an educational point of view, teaching and learning core ideas of non-linear systems contribute to the development of more adequate worldviews in general, and more relevant views of the nature of science in particular (Kimorek & Duit 2004). Based on an educational analysis of the science content structure of non-linear systems (Komorek, Stavrou & Duit 2003), the study presented here focuses on the limited predictability of deterministic chaotic systems. The aim of the study is to investigate if and to what extent pre-service teachers of primary education can develop an understanding of the limited predictability in deterministic chaotic systems.

Methodology

Based on the findings of previous research work in the area of non-linear systems (Duit, Komorek & Wilbers 1997; Skordoulis, Tolas & Stavrou 2005; Stavrou, Duit & Komorek 2008) and of a questionnaire about determinism, predictability, order, chaos and chance, developed especially for this study, a teaching sequence was
designed. In the teaching sequence a commercial chaotic pendulum manufactured by PASCO [http://www.pasco.com, see also Laws 2004] interconnected with a data acquisition interface, is used. The teaching sequence is structured in two parts. In the first part the pendulum carries out a simple harmonic oscillation and in the second part, changing a suitable parameter, the pendulum carries out a random-like/chaotic motion. Data of the harmonic and chaotic motion of the pendulum in form of graphical representations of the angular displacement vs. time ($\varphi = \varphi(t)$) and angular velocity vs. angular displacement ($\omega = \omega(\varphi)$) are displayed in Fig. 1&2.

Figure 1. Graphical representation $\varphi = \varphi(t)$ (left) and $\omega=\omega(\varphi)$ (right) of the harmonic motion.

The empirical investigation is designed as a learning process study. To collect the data, experimental interviews (a so-called “teaching experiment”, Steffe & D’Ambrosio 1996; Komorek & Duit 2004) were used. The teaching experiment may be viewed as a Piagetian critical interview that is deliberately employed as a teaching and learning situation. Eighteen pre-service teachers of the primary education took part in the study. The teachers-students were divided in 9 groups of 2 persons. For each group the interviews lasted approximately 90 minutes. The interviews were videotaped and transcribed. Due to the explorative character of this study, methods of qualitative content analysis are applied (Erickson 1998).

Figure 2. Graphical representation $\varphi = \varphi(t)$ (left) and $\omega=\omega(\varphi)$ (right) of the chaotic motion.
The main part of the interviews could be briefly summarized in the following points:

- Description of the experimental device
- Observation of the pendulum motion and the graphs $\varphi = \varphi(t)$ and $\omega = \omega(\varphi)$. Statements about the existence of deterministic laws, order, predictability, chaos or chance.
- Repetition of the experiment under the same starting conditions.
- Comparison of the graphs $\varphi = \varphi(t)$ and $\omega = \omega(\varphi)$ from the first and the second run of the experiment. Statements about the existence of deterministic laws, order, predictability, chaos or chance.
- Repetition of the experiment with slightly different starting position of the pendulum.
- Comparison of the graphs $\varphi = \varphi(t)$ and $\omega = \omega(\varphi)$ from the previous run of the experiment and the actual. Consequences about the effect of slightly different starting position in the outcomes.
- Development of a representation about the possibility to have deterministic laws without predictability. Reflection on their own representations about determinism and predictability.

Results

The main findings of the study are summarized in the following:

Teachers-students’ representations could be summarized in two schemes: deterministic laws - predictability - order and chaos - chance - non predictability - disorder

The analysis of the questionnaire and the interviews shows that the teachers-students linked closely deterministic laws with predictability and the existence of order and chaos with chance, non-predictability and disorder. Whenever students identified order or the possibility to make predictions they supposed also the existence of a law. And vice versa, if they couldn’t see any order, or couldn’t make a prediction they supposed the existence of a random process. Regularity, periodicity and especially reproducibility are identified by the students as characteristics of deterministic processes. The absence of these characteristics refers to chance or chaos.

In addition chaos and chance are not identical for the students. Chaos is, for them, more “extreme” and includes chance. A random process is seen as not necessarily chaotic. For example, most of the students characterize the random-like/chaotic motion of the pendulum and the form of the graph $\varphi = \varphi(t)$ (figure 2, left) as random but not as chaotic, because the apparent behaviour is not seem as “erratic” enough.

Teachers-students can develop a representation of the limited predictability of deterministic chaotic systems

Most of the teachers-students recognize that it is possible to have deterministic laws in random-like processes without having the possibility of making prediction. They also see that little changes in deterministic processes could lead to totally different results. The occurrence of a similar form of the graph $\omega = \omega(\varphi)$ (figure 2, right) in a repetition of the experiment was strong enough evidence, as to accept a deterministic behavior in the random-like motion of the pendulum. Taking into account the respectively graph $\varphi = \varphi(t)$ (figure 2, left) they conclude that it is possible to have deterministic laws without predictability.
Teachers-Students’ representations of the connection between deterministic laws and predictability as well as between chance and non-predictability cause some difficulties. In the random-like motion of the pendulum, students tried to combine the two graphs $\varphi = \varphi(t)$ and $\omega = \omega(\varphi)$, so that they are compatible with the scheme deterministic laws - predictability and chance - non-predictability. For example, if they started from the graph $\omega = \omega(\varphi)$ (figure 2, right) they looked for regularities in the graph $\varphi = \varphi(t)$ (figure 2, left). As these efforts were not fruitful, they come to the aforementioned conclusion.

Nevertheless, three of the teachers-students did not accept the possibility to have deterministic laws without having predictability. For these student the two graphs $\omega = \omega(\varphi)$ and $\varphi = \varphi(t)$ should be compatible. They did not accept, for example, that the graph $\omega = \omega(\varphi)$ (figure 2, right) could refer to a deterministic process, as there is not possible to make any prediction taking into account the graph $\varphi = \varphi(t)$ (figure 2, left).

Conclusions

This study offer an insight on pre-service teachers’ representations and their learning processes about an aspect of non-linear systems, specifically of limited predictability in deterministic chaotic systems. It shows that the most of the teachers-students can develop a representation of a basic idea of non-linear systems. Moreover, they can differentiate their conceptions about determinism and predictability. To put it in one teachers-students’ own words: “I believed, that whenever a law exists a prediction is always possible. We saw here, that it is not always possible to make a prediction, although a law exists”.

References


THE USE OF BLOGS IN DISCUSSIONS ON CONCEPTUAL KNOWLEDGE

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Abstract

When students deal with theoretical concepts in Science and other subjects, it is of central importance that they have the opportunity to discuss their views and perceptions. In Norway, technology is a central part of the Science curriculum for primary schools. In the present study students have been constructing physical models, and in some of the student projects also digital models, of different types of technological constructions. These activities were linked to theoretical discussions on themes within Physics and Mathematics. As a part of the project, the students were invited to share their ideas and experiences through a blog (web-log). Eight schools participated in the study during the autumn of 2008 and spring of 2009. The activity on the blog varied extensively between schools. In a large proportion of the postings, the students' contributions were limited to descriptions of activity. A smaller number, however, focused on prediction of results and future actions as well as teamwork and collaboration. In their postings, the students used everyday language with no instances of school scientific phrases. The opportunity to make use of the affordances of technology to articulate, share and reflect on scientific invention, can in the future be available through teacher initiative direction.

Introduction

In Norway we have a long tradition of hands-on teaching in science. This seems, however, not to have been a success when it comes to the students’ conceptual knowledge as measured in the recent PISA surveys of achievement (Kjærnsli, Lie, Olsen, & Roe, 2007). There is now a growing focus on the importance on minds-on in the learning process and also in connection to hands-on activity. Opportunities need to be provided for students to engage in discussion to develop and refine conceptual knowledge (Mortimer & Scott, 2003). Aikenhead (1996) noted the importance of verbal communication in learning and found that this can be restricted by the differences between the school culture and the cultural background of each student.

The cited authors located their findings in the physical classrooms. However, access to Internet connected computers is now common in every modern classroom and this means that these discussions can wholly or partly be carried out on the World Wide Web. There are several arguments for taking the trouble to transfer parts of students’ discussions to, for example, blogs (web-logs) where students express their ideas in writing (Dysthe, 1993). The affordances brought by this technology are many. For example, students can write for a real audience and they can use a communication medium that most young people prefer in their private contact with their friends. Furthermore, a blog will make it easier for students to comment on other groups’ projects, both within their own school and between schools. For the teachers it is easy to get information on the students’ progress in the project.
Misunderstandings can be discovered and discussed, and examples from the students’ activity can be used in further teaching. A final affordance related to the use of blogs in student projects is that parents can get a closer look into their children’s learning activity.

In Norway, technology is a central part of the Science curriculum for primary schools. In the present study (part of a larger cooperation with schools in Australia), students have been constructing physical models, and within some of the projects also digital models, on different types of technological constructions. These activities were linked to theoretical discussions on themes within Physics and Mathematics. Students in the eight participating schools were invited to share their constructions with their peers through a blog. As well as the previously described affordances, the use of blogs also has the potential to enhance student motivation or engagement. Chen and McGrath (2003) defined motivation and engagement as comprising of enjoyment, concentration, control, exploration and challenge. As all these elements were embedded in the students’ projects and would be enhanced by being active in the online discussions, we expected to see high levels of student participation. The results, to be discussed later, showed a rather mixed response from students in both the frequency and content of their submissions.

Rationale

In order to reveal how blogs can be used in teaching and learning, we will focus two questions:

- Do students make use of school scientific phrases in their blogging?
- Is the students’ focus in blogs mainly descriptive or do they also focus innovative and collaborative aspects?

Methods

The present study took place during one or two weeks in autumn 2008 and spring 2009 and includes students from Year 3 to 9 in eight primary schools located in the western part of Finnmark County in Northern Norway. A total of approximately 195 students participated typically organized in groups of 2 to 4 students; except for one school where each student made their own construction. The schools were of differing sizes and will be referred to as School A-H. The number of students varied between a total of 15 students at the entire school to 45 students at a specific year level.

The data for the study is taken from student postings and teacher interviews. All schools used Googles blogger.com as host for the blogging. Students’ use of school scientific phrases in the postings and comments was evaluated at a 3-point scale (lacking, to some extent, frequently). Postings were categorized in four groups in accordance with Lloyd and Duncan-Howell (2008): (1) Description of activity; (2) Predicting results / future actions; (3) Evidence of trials / modifications; and (4) Evidence of teamwork / collaboration. Two researchers analyzed the postings and, where results differed, agreement on which category a given posting should be within were based on discussions between the researchers.

During the project, or soon after termination of the project, teachers were interviewed. They were asked open-ended questions relating to previous use of ICT and on their perceptions of student engagement during the project.

Results

None of the schools (n=8) included in the present study had any previous experience in using blogs as a part of student projects. The students seemed to depend on the teachers’ initiative and direction in order to make use of the blogs. During the project a total of 163 postings were analysed, of which 24 harboured two categories, thus...
making a total of 187 student statements. Both the relatively low number of postings per student group and the low ratio of comments per posting support the argument that this type of activity is not common practice within the schools participating in this project.

The students typically used their everyday language in the blogs where school-scientific phrases were lacking. The postings were written in Norwegian and we here present some examples after translating them to English almost word by word:

- **Cat.1- Description of activity**: Today I finished my house and painted it, today I started fixing the house. Then I started drawing one wall of the house on cardboard. It’s tiring that I have to be so accurate. (Year 9)

- **Cat.2 - Predicting results/ future actions**: This is the third day using SketchUp. … Tomorrow we start making the real model. (Year 8)

- **Cat.3 - Evidence of trials/ modifications**: Today has been a special day; I found a lot of new functions in SketchUp. As to find out how to make the aeroplane hollow inside. I was working hard for at least half an hour (Year 8)

- **Cat.4 - Evidence of Teamwork/ collaboration**: Today we made models in SketchUp. I and Anne had problems deciding which model to go for, mine or hers. Now we have made our choice :-) (Year 8)

A significant variation in the rate of blogging appeared between schools, which, to us, seemed to depend on the teachers’ initiative. For example, it seemed important that the teachers included blogging as a part of the program for the day.

As noted, student blogs and comments were coded within the four categories derived by Lloyd and Duncan-Howell (2008). This coding showed that more than half of the postings were restricted to a description of the activity that had been carried out during the constructions of data models and/or physical models (Category 1). A minor focus was given in predicting results and future actions (Category 2) and to teamwork and collaboration (Category 4) (see Table I).

### Table I Coding of student posting

<table>
<thead>
<tr>
<th>School</th>
<th>Category 1: Description of activity</th>
<th>Category 2: Predicting results/ future actions</th>
<th>Category 3: Evidence of trials/ modifications</th>
<th>Category 4: Evidence of teamwork/ collaboration</th>
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Conclusions and Implications

Technical problems did not seem to have limited the use of blogs in the current project. Rather, there seems to be some challenges related to previous school traditions and to teachers’ initiative when it comes to this type of use of ICT (see also John & Sutherland, 2005). Schools and teachers who want to include blogs as a part of the students’ learning strategies need to focus on the possibilities given by this type of web-based communication as a part of the progress in a given project. In a similar project (Lloyd & Duncan-Howell, 2008), Australian students were seen to use blogs as an area for discussion more frequently than the Norwegian students did in the present study. Furthermore, the Australian students focused on teamwork and collaboration to a larger extent in their postings (close to 50%, cf. 7.5%), while the Norwegian students predominantly focused description of the activities (51.3%). This difference may be related to lack of tradition in Norway both with technology as a theme within schools and with the use of online communication in student projects.

The lack of school scientific phrases in the students’ postings should be expected since most young people probably use blogs as part of their private communication with friends. At school, when students blog on their projects, they probably continue the private tradition, that is, they adopt highly informal structures in their writing (John & Sutherland, 2005).

Should we then conclude that blogs cannot be used for discussions on conceptual knowledge? To our interpretation, it all depends on the direction the teacher gives to the students in using the blogs. Her role will partly be to challenge the students on theoretical concepts through comments on their postings and partly to use examples from the postings in her own teaching. In that way students’ experience during hands-on activity can be linked to the discussion on conceptual theory. This study has shown that there is potential for the use of blogs to develop students’ learning but that changes are needed to school culture and teacher confidence and familiarity in its use.

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LEARNING SCIENCE EFFECTIVELY IN LABORATORY:
CONSTRAINTS AND ISSUES

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Abstract

The science laboratory is central to science teaching. The two most important goals with lab work are to act as a link between theory and practice and to offer laboratory skills. To learn effectively, laboratory environment should be design to give opportunities for students to collaborate, sharing ideas and experiences and get feedback on their learning. Therefore learning environment should be design to suit the needs. This paper will present the current situation of the laboratory and its suitability for effective science teaching and learning.

Introduction

The science laboratory is important to science teaching and it offers a different environment from traditional classroom (Henderson & Fisher 1998). The laboratory work has the potential to engage students in authentic investigation in which they can identify the problem to investigate, design procedures and draw conclusion. These activities can give students a sense as to how scientists go about their work, which in turn may influence their attitudes about scientific enterprise (Chiappetta & Koballa 2006).

Along with that, laboratory work can help student acquire a better understanding of concepts and principles as a result of concrete experiences (Freedman 2002). These parallel with social constructivism perspective, where students can develop more scientific concepts in dialogue with peer when they interact with problems which are meaningful and connected to their experiences (Lunetta 1998) and with representatives of the expert community (teacher, textbooks, etc.). In connection with that, it is vital to provide learning environment which can give opportunities for students to collaborate, sharing ideas and experiences and get feedback on their learning (KPM 2006; Kijkosol 2005). This is because; researches have shown that learning environment can affect behavior of both students and teachers (Savage 1999; Stewart & Evans 1997; Weinstein 1992). The architecture of the physical space exerts its influence on the behavior in an indirect way, promoting specific forms of social organization (Matai & Matai 2007).

This study tried to identify the features of the physical learning environment and develop science classroom that could cater for the various kinds of pedagogies that meets learner’s needs during 21st century such as using technology, teamwork and taking responsibility for one’s own learning but this paper only present one part of the research which is the current situation of the laboratory and its suitability for effective science teaching and learning.
Rationale

In Malaysia, science curriculum has periodically undergone reviews which aim at improving science teaching and learning (PPK 1992, PPK 2001d). Along with that, innovative teaching and learning strategies are being disseminated to the teacher. For example, the use of pedagogies based on theory of situated learning (Brown, Collins & Duguid 1989) and social constructivism theory (Berk & Wintsler 1995; Hassard 2006) which emphasized on active as well as collaborative and technological related skills.

However the science classroom design and environment do not reflect the needs of these new pedagogies (Ahmad Fauzi Wahab 2005; BPPDP, KPM 1997; Education Development Master Plan (PIPP) 2006-2010). In the science laboratory, tables and chairs still arranged in rows facing the teacher. These design support the transmission theory of learning which emphasis on pedagogy teaching as telling (Bransford et al, 1999; Chism, 2002), which also inhibit or limit the interaction between teachers and students (Rohaida Mohd.Saat dan Kamariah Abu Bakar 2005).

Additionally, with the implementation ETeMS (English for Teaching Mathematics and Science) in 2003 and the integration of ICT as a tool in teaching, the science laboratory now not only use for conducting investigation but it also serve as a place for teaching and learning science. Therefore science laboratory learning environment should be flexible enough to accommodate these two different roles.

Methods

The study used a qualitative method and all the data were collected using interviews and discussion with experience teacher (more than 10 years teaches science). Face to face interview have been done with teachers in order to get information about the constraint that they faced while teaching science especially related with the science laboratory learning environment.

Results

From the teachers’ perspective, there are few constraints and issues related to the existing science laboratory in Malaysia which are:

a. The design of furniture in the laboratory was not satisfactory. The table surface is not resistant to heat or acid, locker under the table limit the space for students’ feet, the location of sink in the middle of table and the gas pipe on the table is not appropriate especially during teaching and learning process. In addition, the wood stools uses in the laboratory were not comfortable to sit on in a long time during teaching and learning process.

b. The arrangement of furniture in the laboratory is fix and cannot be manipulated to suit the various teaching and learning strategies. Beside that, the spaces between tables were not wide enough and limit the students and teachers movement. Class can be crowded especially when there are too many students in a class (Malaysia context, 35 students)

c. Limited technology such as computer and internet. Computer provided only for teacher, there is no computer for student and no internet access in some of the laboratories. Teachers’ complaint that the white screen blocked the blackboard and should appropriate in size so that the entire student can see the presentation clearly.

d. According to some teachers, science equipments and apparatus still not enough and in some school, the electric and water supply in the laboratory were not consistent. In conjunction with that, safety items also not complete in some of the school.

e. The learning environment was not conducive where some teacher complaint that the laboratories become too hot especially during afternoon class and the student cannot concentrate to their study. There is also disturbance from noise if the laboratories located near the road or construction sites
Conclusions and Implications

The study showed that there are constraints in the science laboratory environment in Malaysia which need to be addressed in order to increase the effectiveness of teaching and learning science. Teachers and researchers have suggested a few elements to be considered in designing laboratory environments. Among these are:

a. The combination laboratory with science classroom

The combination of a science classroom with laboratory provides ongoing access to laboratory activities for each class (Motz et al. 2007). Significantly, more hands-on activity and inquiry teaching happen in this integrated space because students can switch from discussion methods to investigation and back to discussion in same learning period (Englehardt 1968; West, Motz & Biehle 2000). Furthermore, this space provides maximum instructional options and flexible use of space for various types of instruction as well as allowing more student-centred and concrete learning opportunities.

b. Incorporate flexibility in design science laboratory

Science laboratories are expensive when it comes to equipment and maintenance (OECD 1999), therefore careful planning is needed to cut down the cost. One of the important features recommended by many researchers is to incorporate flexibility in science laboratory design (School Construction News 2005; Motz et al. 2007; Arzi 1998). Ideas for flexible designs of science laboratories range from movable furniture to movable internal walls and from peripheral to central location of services (Arzi 1998). However, total flexibility in each and every feature cannot be attained and compromises have to be made and creative design and construction solutions are needed (Arzi 1998).

c. Integration technology with laboratory

Technologies expand science learning space into the world around and nowadays, the global classroom is a reality. Science classroom should be designed with multiple access points to the internet and the world (Motz et al. 2007).

It is essential to provide telephone for voice communication, appropriate media for video and computing devices for data processing. In addition to computer, scientific instruments and many kinds of technological equipment are also needed in science laboratories. This because technology can influence interactivity in science classroom and with the use of laptop or PC which connected to internet, students and teachers can find out extra information in the web, involve in collaboration or use object to illustrate concepts (Lomas & Diana 2006).

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Plan Induk Pembangunan Pendidikan (PIPP) 2006-2010. Bahagian Perancangan dan Penyelidikan Dasar Pendidikan,Kementerian Pendidikan Malaysia


PROMOTING HIGH QUALITY IN UNDERGRADUATE UNIVERSITY SCIENCE TEACHING

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Abstract

In this symposium, four empirical studies on university science teaching were reported. The first two studies concerned courses aimed at preparing science faculty to teach undergraduate courses. The other two studies concentrated on the teaching practice of experienced science faculty. Taken together, these four studies made several things clear. First, the training of future science faculty can be quite effective if courses provide prospective faculty with opportunities to design and teach lessons, while simultaneously challenging their belief systems. Second, examinations of the views and the practice of experienced science faculty revealed specific relationships between teachers’ knowledge, their views on teaching, their intentions, approaches and teaching behaviours.

General introduction

Most undergraduate science college courses are traditionally taught through large lectures (Shipman, 2004). The course syllabus often covers a vast array of topics, with few, if any, laboratory experiences. In course evaluations many students report poor teaching. In Talking about Leaving, Seymour and Hewitt (1997) describe their comprehensive study of why undergraduates choose to remain in science, mathematics, or engineering [SME] related majors, or choose to leave those majors. Of all students in their sample, 83% stated “poor teaching” was a concern, and for many this was an important reason to give up a major in SME. Although there have been calls to reform undergraduate instruction for over 100 years (Pitkin, 1909), change is slow (Gess-Newsome et al., 2003). Both personal and contextual factors contribute to faculty resistance to alter instructional style from ‘transmission of information’ toward a constructivist style where students are active learners. Clearly there is a need to examine undergraduate science teaching practices and prepare future science faculty to be more effective teachers.

In this symposium, four empirical studies, conducted in research-intensive universities, were reported. Each study focused on a different aspect of the problem outlined above. The first two studies concerned courses aimed at preparing science faculty to teach undergraduate courses. In these studies, a particular emphasis was on the emerging teaching philosophies of the participants, on their views about the nature of science, and on how their reflections on practical experiences shape their teaching competences. The other two studies concentrated on the teaching practice of experienced science faculty. In the first of these studies, teachers’ cognitions and emotions regarding the teaching of specific topics (i.e., in quantum chemistry) were investigated in relation to each other. In the final paper, the congruence between teachers’ intentions and their teaching practice was studied.

Taken together, these four studies made several things clear. First, the training of future science faculty can be quite effective in bringing about changes in teachers’ philosophies of teaching, in combination with developing their teaching skills. To achieve these results, courses should provide prospective faculty with opportunities to design and teach lessons, while simultaneously challenging their belief systems. Second, examinations of the views and the practice of experienced science faculty revealed that teachers’ PCK appeared to be related to specific emotional aspects of their views on teaching subject matter. Also, teachers’ intentions, approaches and teaching behaviours
appeared to be related in a congruent way depending on specific factors (e.g., a large degree of freedom to design one’s own courses).

References


Abstract

In this paper I describe the nature of a new university course on reformed-based pedagogy offered at a research-intensive university in the United States, and report on its influence on prospective college teachers’ views of teaching science. The course, Innovative Teaching in the Sciences (ITS) targets science doctoral students who plan to teach in higher education or extension work, and is designed to shift the focus from primarily transmitting science facts through large lectures, to engaging students in active learning, inquiry, and nature of science, aspects of reformed-based science teaching as articulated in reform documents for K-12 education in the U.S. The research design used an interpretive, qualitative approach (Creswell, 1998; Miles & Huberman, 1994) and involved gathering multiple data sources, including course products and responses to a Pre-course questionnaire. Students began the course with naïve views of what it means to teach science as inquiry and developed more robust philosophies of teaching science. In final espoused statements all students showed movement towards student-centered and inquiry-based approaches. The findings of this study add to the limited research on inquiry-based teaching at the college level.

Introduction

Most undergraduate level science college courses in the U.S. are traditionally taught through large lectures (Shipman, 2004). A college science course syllabus often covers a vast array of topics, with few, if any, laboratory experiences. In course evaluations many students report poor teaching. There is evidence that students do not necessarily develop understandings of science concepts through lecture-based classes, when there is little student input or engagement (see NRC, 1996, 2000). To address this situation the United States published guidelines for changing the way science is taught in higher education (National Science Board, 1996).

However, it is difficult to overcome the inertia of large lecture formats, especially in poor economic times. Yet, some changes are apparently taking place, in the way science is taught in undergraduate level courses (Shipman, 2004). There is a gathering movement towards using new ways to teach science at the university level. Although there appears to be interest in inquiry-based instructional practice, there is little empirical evidence that things have changed in the ways professors generally teach undergraduate classes. There have been a few studies published focused on inquiry teaching in higher education. One study researched three college professors, as they designed and taught inquiry-based classes (Gess-Newsome, Sutherland, Johnston, & Woodbury, 2003). Yet, many college professors have a narrow view of inquiry-based instruction, and believe this kind of instruction takes too much time to warrant changing from direct teaching and large lecture format (Brown, Abell, Demir, & Schmidt, 2006).

I am a science teacher educator whose primary focus is clearly centered on preparing secondary level (U.S. ages 11-18) science teachers to teach in reformed-based ways, and in supporting in-service teachers in engaging students in gaining deep understanding of key science concepts, and in understanding what science is, and what science is not. My main goals include changing the way science is taught in most science classrooms. Students in my methods classes are generally preparing to teach biology, physics, chemistry, and earth science at the pre-college level. My prospective science teachers often report to me that they have inadequate educational experiences in their
introductory undergraduate science content courses, where they are often forced to memorize huge volumes of information, and they become frustrated with multiple-choice examinations. Recently, I designed an elective graduate level course for doctoral students, who are interested in teaching in higher education. The target audience includes graduate students engaged in high-level science research projects at a large top-tier research institution. The new course titled. Innovative Teaching in the Sciences (ITS), was designed to shift the focus from transmitting science facts through large lectures, to engaging students in active learning, through using inquiry-based approaches (i.e. Schwab, 1962), and learning about nature of science and use of critical thinking-- aspects of reformed-based science teaching as articulated in documents aimed at K-12 level teaching (Anderson, 2002; NRC, 2000). Conscious effort was made to model inquiry teaching methods as part of the course.

This paper is the result of conversations with colleagues at a national conference on research in science teaching in the U.S., a few years ago. By coincidence we discovered we were all exploring how to support prospective college instructors in teaching science, not as a litany of facts, but as inquiry and by understanding nature of science. We agreed to examine the influence of our courses on students' views of teaching science.

In this paper I describe the rationale for the design of the course in teaching and learning and its influence on prospective college instructors' views of teaching. The course combines reading empirical research on learning and teaching science, class discussions on inquiry and nature of science, strategies for teaching, alternative assessments, learning technologies, and opportunity for lesson design and peer teaching. A central aspect of the course is the development of a personal philosophy of teaching and learning science, with an eye towards innovative teaching.

**Theoretical Framework**

The theoretical framework of this study includes constructivist perspectives of learning and teaching; the view that children and adults learn through engaging in experiences and structuring their understandings based on these experiences (Brown, 1994; Cobb, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994). The view that learners need be active in thinking processes in order to develop their own robust understandings, is embodied in constructivist views of learning. A social constructivist view of learning involves the negotiation of ideas among people in conversation and debate (Brown, et al, 1989; Solomon, 1989, 1993; Vygotsky, 1978; Wood, Cobb, & Yackel, 1992) that also frames both the design of the course, and the design of the study and analyses focused on collaboration and negotiating understandings (Crawford, Krajcik, & Marx, 1999).

**Research Design and Data Sources**

The research design used an interpretive, qualitative approach (Creswell, 1998; Miles & Huberman, 1994) and involved gathering multiple data sources, involving course products and responses to a questionnaire. I was interested in my students' initial goals, the development of their philosophies of teaching and learning, and changes, if any, in their philosophies and their views of inquiry, nature of science and inquiry-based pedagogy. None of the data were gathered external to the normal course requirements. One data source was the Pre-course Questionnaire (see Appendix A). Students’ goals and educational backgrounds were collected on-line, immediately after the first class session. Also, questions targeted prior research experiences and initial views of inquiry and nature of science, as well as central aspects of their current philosophies of teaching. An important data source was each student’s espoused philosophy statement, written in the early part of the course and revised towards the end of the course. I developed a coding/scoring guide based on the essential features of inquiry, and aspects of nature of science found in the literature. I coded these philosophy statements and determined pre and post numerical scores, in addition to qualitatively analyzing the writings as a whole. Data included lesson plans designed and carried out for their peer teaching episodes as a normal part of the course, viewed for features of inquiry and nature of science. In designing their lessons each students selected a science concept or principle related to his or her research area.
Twenty students formally enrolled in the course. Some of the twenty students were education doctoral students who had taken other education courses. I did not include their work in the study, as I was interested in how prospective college teachers with little prior experience in education coursework might change their views as the result of taking a single course. The study sample consisted of ten students who took the course for college credit and who intended to go on to teach in higher education; and who did not have prior education coursework. Their fields of study included horticulture/apple breeding, food science, evolutionary biology, plant breeding and genetics, electrical engineering, chemical biology, ornithology, mathematics and computer science, and biology. My university has a policy that allows students to “shop for courses” the first three weeks of the semester. Although I expected at the most, eight to ten students would register for the course (this is an elective graduate seminar style course), more than 25 students showed up for the first class. Interestingly, some of my students confessed their major professor had cautioned them that the course would take precious time away from their laboratory research. Yet, they came. Some chose to audit the class, fearing the assignments might take too much time away from their research; a few were on the job market interviewing for positions as post docs or faculty in other universities. One student dropped the class after the third class session, having never officially enrolled in the course. In this case, dropping the course may have resulted in part from my clear emphasis during the first class sessions on a view of learning and teaching science quite foreign to this particular physics student. During discussions, this student vehemently argued with other students about what science is, and struggled with understanding the point of the readings in learning how to teach science. A second student, halfway through the semester, confessed he would not have time to complete all the assignments; he would be willing to take an F (failing grade), if he could just continue to come to the class discussions. He found these discussions valuable, but he felt swamped with his own laboratory work. These aforementioned students’ course products and questionnaires were not included in the data set for analyses.

The rationale for using designed lesson plans as evidence of students’ intentions and views of teaching science as inquiry stems from the assumption that these students have more freedom in topic selection and using innovative approaches, as compared with student teachers in a pre-college teacher preparation program. I claim, it is appropriate to infer from their designed lesson plans, the nature of these prospective college instructors’ views of teaching and learning science. Research questions include the following:

1) What are prospective college instructors’ emerging philosophies of teaching, and how do they change, if at all, during the course?

2) What is the evidence that prospective college instructors develop an understanding of teaching science as inquiry?

The Nature of the ITS Course

The goal of the ITS course is to prepare college science instructors to facilitate the intellectual growth of their students as critical thinkers, while providing those students with a robust personal understanding of the nature of science; using innovative, student-centered, inquiry-based instruction as a substitute or supplement to traditional style instruction. A section of the course description states:

This course combines the research on learning and teaching science, with the pedagogy and practical applications for teaching science at the college level, as well as extension and in informal settings. The instructor emphasizes how to design effective learning environments that actively involve students in critical thinking. Innovative Teaching in the Sciences addresses a variety of instructional approaches, including problem-based, collaborative learning, model-based, community-based, and the use of authentic contexts. Examples are grounded in practice. Readings focus on the empirical research related to this kind of teaching, including issues of gender and underrepresented populations in science and math and engineering, and highlights the benefits of using inquiry-based teaching approaches, as well as challenges and pitfalls.
My goal was to enable prospective college instructors to develop instructional plans and design learning environments that support in-depth learning of key concepts and an understanding of the nature of science through inquiry (Schwartz & Crawford, 2004). In one of the key assignments students are asked to do the following:

Design of Inquiry-based Instruction and Peer Teaching:

You will identify a set of concepts or principles in your discipline, formulate a *Driving Question*, and design an innovative instructional plan (lessons/labs) for use in your particular teaching situation. You will use the principles of inquiry-based instruction gained from readings and class discussions, and 1) present an overview of your instructional design to the class; and 2) teach a segment of a lesson to your peers for feedback.

The course syllabus lists questions, not topics. Questions included, what are your views of teaching and learning? what is the problem with how science is usually taught? what are new perspectives on teaching and learning? During the first few class sessions (these were 2 ½ hours one day a week), I shared my views of what it means to “teach science as inquiry”. Instead of using a direct teaching method (i.e. listing the steps for how to develop the best lecture or the best PowerPoint presentation or delivering handouts on best practices) I asked my Ivy League university doctoral science students this question, can you light a bulb with one battery and one wire? I handed around the batteries, the bulbs, and the wires. I then showed them a flashlight, turned it on, and asked them to draw a model of what is inside a flashlight. They shared their models with the person sitting next to them (electrical engineers with chemical biologists). Building on these personal experiences I showed a well-known video clip from the Private University study of M.I.T. graduates, who were asked to take on the same task, yet stumbled in their attempts to give scientifically accurate explanations. I further modeled an inquiry-based approach by engaging students in a series of activities; all involving a scientific question, the use of observations, gathering data and evidence, developing explanations, and justifying their explanations. After each experience I stepped back, and deconstructed what had happened in the lesson. One of the modeled lessons, Fossilized Tracks, is described in the NRC book, *Teaching Evolution and Nature of Science* (1998). Students develop a story of how two sets of tracks were laid down and fossilized. What happened? What is the evidence? What are your observations? What are your inferences? Did your story change after hearing others give their story? At each step I engaged my science doctoral students in a whole class discussion of a lesson, originally designed in the 1960s for elementary students. Another model lesson was the Cube lesson (NRC, 1998). We discussed aspects of Nature of Science (NOS) that one could teach using this lesson--that science is empirical, subjective, a product of human imagination and creativeness, and the distinction between observations and inferences (Lederman, 1992).

Near the end of the session I shared what I mean by "teaching science as inquiry" –that of grappling with data and developing explanations of an event or phenomenon; of answering questions based on evidence and connecting developing understandings to the scientific understandings (see NRC, 2000). At the center of an inquiry-based approach is the student herself, making sense of something; of figuring out what is an explanation based on evidence, the process of grappling with data. I go on…isn’t this exactly like how a scientist works? Like what you do? So, why don’t we teach our students in similar ways to how scientists work and think?

I asked these doctoral science students to read journal articles of science educational research (e.g. Furtak, 2006; Hodson, 1986; Schwartz, Lederman, & Crawford, 2004) and we debated the findings and significance of these readings in small groups. One central assignment was that of developing a teaching philosophy statement, which could later be used in an application for a teaching position in higher education. The entire course syllabus, including the list of readings and description of assignments and class discussions, is available by email request of the author.
Findings

From analyzing the Pre-course Questionnaire, it was evident that although prospective college teachers expressed clear interest in teaching, most had had no formal experiences in learning about pedagogy. For example, Mary (pseudonym) was a 4th year Ph.D. student in Evolutionary Biology. In response to the pre-course questionnaire question, #6, List your previous education coursework, if any, she responded, *I have not had the opportunity to take any education courses before now*. Another student, Kelly, a 1st year graduate student in Food Science/Food Chemistry, wrote, *the only thing I have done is I was an undergraduate TA and writing tutor for a few years*. A third student, Miriam, was a doctoral student in Chemical Engineering. Like many of the students at this research-intensive university she had no prior formal educational experiences, other than serving as a TA.

In response to the question, what are your primary goals for this course?, a few students mentioned inquiry, and based their pre-philosophies on models seen in previous courses they had taken. Mary, stated,

*My main goals for this course are improving my teaching skills. I intend to be a professor, and in Ecology and Evolutionary Biology at (this university) the focus is very much on research to the exclusion of teaching. Teaching is viewed as “something you just go and do”, but I want to be more prepared than that. A particular undergraduate course that employed inquiry based teaching methods was instrumental in my eventual career path; I would like to develop skills in this area so I can provide my students with similar enrichment. I am particularly interested in learning how to integrate inquiry-based instruction in the large, structured lecture-based classes I will be teaching.*

Kelly stated,

*My main goals for this course are: ways to get students excited about the sciences. Too many people that I have met are afraid/intimidated by Chemistry (my first love ☺) and the other Sciences. I’d love to find a way of introducing material to students that will cause them to open their minds instead of just saying, “I don’t get it”.*

Miriam, a doctoral student in Chemical Engineering, represented a more traditional view in her desire to be efficient and cover a lot of material. Miriam, stated simply,

*My main goals for this course are: find the best way to teach a lot of science in a short amount of time.*

Related to the first research question, *what are prospective college instructors’ emerging philosophies of teaching, and how do they change, if at all*, there was evidence that during the course these students had intuitive ideas about teaching science, and later evolved more robust philosophies of teaching during the course. Prior to taking the course all students expressed an interest in teaching. Indeed, that was the reason they signed up for the course. Their initial beliefs about teaching and learning were varied and mostly stated in intuitive/everyday language, grounded in their unique personal learning experiences. Many confessed they had never been asked to write a philosophy of teaching statement. In response to question #7, state what you would consider the central aspect of your current philosophy of teaching, most were cautious about putting forth their ideas. Early in the course Rachel (Ornithology) stated, “I’m not sure that I could currently articulate a philosophy of teaching.” Kelly (Food Science) wrote, “To be honest, this is something I hope to develop throughout this class and I do not have a concise philosophy of teaching”.

For those students who identified a central aspect of their philosophy, they focused on student motivation and interest and the enthusiasm of the instructor. These students had some ideas, gained from their own interest in their discipline. Roland, a doctoral student in computer science and artificial intelligence wrote, “My objective when teaching any subject (be it first-order logic, training artificial neural networks or basic photographic technique) is to transmit my enthusiasm and love for the subject to my students. I want my students to experience the same sense of wonderment I have felt so many times when studying these topics.” Juniper a 2nd year doctoral student in plant
breeding and genetics wrote, “In order to really learn anything, a student must first have interest in the subject, so therefore the key to learning is first stimulating interest. Jeremy, wrote, “The central aspect to my current philosophy of teaching is that any student can be great in any field as long as they have the interest and willpower to push forward. It is a teacher’s responsibility to cultivate that interest.” Another example of this emphasis on student motivation and interest is Janine’s response to Pre-Question #7: “I think motivating my students is crucial. Helping them see that they are capable of achieving success. As a woman, I also want to help girls become comfortable with being ‘smart’, and good at science.”

Students’ early philosophy statements were crafted from their personal learning experiences in both formal and informal education. Although their statements were true representations of their ideas of teaching, their ideas were not grounded in research, learning theory, aspects of teaching science as inquiry, or nature of science, as described in contemporary reform-based documents. As the course progressed these prospective college teachers revised their initial ideas. In “final” philosophy statements they included specific aspects of inquiry and nature of science and constructs such as constructivism. These emerging philosophy statements were all unique; students wove their initial intuitive ideas into a fabric of theoretical ideas gained from the course readings and class discussions. An example from a final philosophy comes from that of Kelly’s:

…My underlying goal as a teacher is to instill this similar ability upon my students and expose them to the world of science. I will implement components of constructivism, where my students will learn from their experiences, and the role of inquiry by connecting concepts to their everyday lives and encouraging them to explore new topics. I hope that they develop a true understanding of various chemical principles and learn how to critically think, so they can apply their knowledge to solve future problems that they may encounter. Ultimately, I want all of my students, despite their background, to learn how to think like a scientist by questioning aspects of their everyday lives and drawing conclusions based on evidence that they gather.

In their final philosophy statements all students specified several aspects of inquiry and nature of science, as illustrated by Kelly’s excerpt. Kelly included two of the essential features of inquiry, that of questioning aspects of everyday life, and the use of evidence. A doctoral student in computer engineering, Lance struggled in early class sessions. He stayed after class to clarify some unsettling points in the readings. He and his office mate had debated the value of using these inquiry-based approaches versus more didactic and lecture-based approaches. In his final philosophy statement he wrote eloquently, “the key message to communicate here is that science (and math in particular) is not straightforward. That there are often many paths to the same goal.” Due to a demanding research schedule one student submitted her philosophy at the end of the semester, “This is really late, but I still found it valuable to do. I found a reference to "transmission of information" in my old philosophy from grad school, so I rewrote almost the entire thing from scratch.” Dean, a doctoral student in chemical biology, wrote:

Science is driven by the individual scientist’s passion for learning and curiosity about the world and is built on the construction of knowledge through interactions within the scientific community. I acknowledge that providing students with authentic experiences in doing science is essential and as such, I will employ teaching strategies that involve inquiry and collaboration. I will teach laboratory courses which involve authentic questions and real-world problems that will engage students and develop their analytical and critical thinking skills as they design experiments, gather and process data, infer conclusions, justify claims and present their results to their peers.

Analysis of Audrey’s pre-, early and later philosophy statements illustrate qualitative differences showing enhancement of views of teaching science as inquiry typical of the other students in this class. (See Table 1.) Results of analyzing Pre-, early and later philosophy statements for inclusion of aspects of inquiry and nature of science for the ten sample students are shown in Figure 1. Students included on average more than six aspects of inquiry and NOS in their final philosophies, versus none in their pre-philosophies.
To answer the second research question, 2) what is the evidence that prospective college instructors develop an understanding of teaching science as inquiry, a comparison was made of students’ Pre-views of inquiry and features of inquiry in their developed lesson plans. Lesson plans were viewed for the essential features of inquiry (NRC, 2000). For the purpose of this paper, an in-depth systematic analysis was not performed; but rather a qualitative comparison made in order to get a sense of the kinds of lessons these students developed, and if, indeed, there were features of inquiry in goals and lesson components. Evidence of understanding what it means to teach science as inquiry included objectives of the lesson, sequencing of lesson components, and opportunity for students to grapple with data, use evidence to develop explanations, and draw conclusions. In contrast, a lesson characterized as traditional and teacher-directed might depict students passively receiving subject matter information (primarily through note taking, lecture, or reading), with limited time for discussion and debate.

Table 1. Qualitative Comparison of Audrey’s Pre-, Early and Later Philosophy Statements

<table>
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<th>PRE Excerpts</th>
<th>Early Excerpts</th>
<th>Later Excerpts</th>
</tr>
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<tbody>
<tr>
<td>Learning can and should be fun.</td>
<td>(1 ½ pages total)</td>
<td>I love horticulture. There is very little more satisfying to me than planting a tiny seed in the spring, and watching that seed sprout, grow, and mature into a giant watermelon, or mighty oak over the months and years.</td>
<td>(3 ½ pages total)</td>
</tr>
<tr>
<td>Some of the best teachers I have had were the ones who were not afraid to put themselves out there, and be a little foolish in order to inspire their students, or make something interesting that might otherwise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Boldface added by author indicating emphasis on motivating students</td>
<td></td>
<td>Essentially, though, the core of my teaching philosophy centers around the belief that inspiration is the food of the spirit.</td>
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</tr>
</tbody>
</table>

On the Pre-questionnaire, most students attempted to give a response to question 8, what is inquiry-based science teaching? A typical response mentioned something about “answering questions”, but the statements were vague. Rachel (3rd year Ornithology) wrote, “I think it’s when you have the student try to figure out the lesson for themselves through experimentation, but I don’t really know.” Andrea, a doctoral student in Plant Breeding, wrote, “I would think this is a teaching method where you either ask a question or have the students ask a question, and then go about trying to figure out the answer. But that is just a guess...” For their designed lessons students addressed a range of sophisticated concepts including, Einstein's Special Theory of Relativity, Animal Behavior, Introductory Algorithms, DNA, Fossils, Nonlinear Dynamics, Computer Engineering, and Proteomics. Their instructional designs ranged from a few pages to chapter length descriptions. Excerpts from instructional plans appear in Table 2.
It is evident these prospective college instructors included at least some aspects of the essential features of inquiry, student-centered strategies, in particular focusing on scientifically oriented questions, use of critical thinking, and promoting collaboration. A surprising outcome of the ITS course was the fact that, on their own initiative, a few students strived to translate their own research into actual teaching episodes for precollege teachers to use in their classrooms, and for the public. Some students wrote and published articles in peer reviewed teaching journals on how to transform their scientific research to make it more understandable to pre-college students. Others included an additional chapter on inquiry-based teaching in their final dissertation.

Discussion and Conclusions

Students began the course with naïve views of what it means to teach science as inquiry and developed more robust philosophies of teaching science. In final espoused statements all students showed movement towards student-centered and inquiry-based approaches. The prospective instructors in this study had a personal interest in enhancing their abilities to teach science. They attended the ITS class, in spite of other pressing obligations to do research and publish scientific findings. For the most part, they were open to change. They thought about, and in many cases, appeared to embrace new ideas about aspects of nature of science, something most of them had not thought about before. They strived to understand what it means to teach science as inquiry, and to develop plans they might actually use in their future teaching.

Whether or not these prospective college instructors will go on to actualize these ideas in their future courses, they were at least open to exploring the language and concepts. In each case, these prospective college teachers did not simply list the essential features of inquiry and nature of science, but tried to weave them into their original philosophy statements, and to connect their developing ideas with their areas of science. In final course evaluations they rated the class discussions of the readings, as the most important component of the course. Some of them saw themselves in the readings, remembering their early college years and feeling that science is often inaccessible; due to the way science is taught in many universities (Tobias, 1990). The findings of this study add to the limited research on inquiry-based teaching at the college level. It is true that these students were poised for change, and changes seen in these students would likely not be seen in a more reluctant sample. Changes in prospective college teachers’ personal philosophies paralleled those of prospective secondary science teachers in a previous study (Crawford & Lunetta, 2002). The importance of college teachers developing a wholly owned philosophy of learning and teaching science aligns with findings of Gess-Newsome et al. (2003). Personal philosophies or practical theories need time and support for development. Prospective college teachers have few non-traditional experiences from which to draw upon, nor do they have the language or access to research to develop their ideas. The main avenue for change in the way science is taught at the college level may be in developing robust philosophies that guide an instructor in enacting inquiry-based approaches when designing and teaching a course.

Implications for College Science Teaching

Shipman (2004) optimistically suggests that, regarding college science teaching, the times they are a changing. Yet, as the world economy struggles, the times may not be a changing after all, in most undergraduate introductory college science lecture halls. I serve on a university ad hoc committee to completely restructure introductory biology at my university. What is unclear after two years of planning is the actual amount of support in terms of TAs these biology professors will receive, as they work towards including inquiry-based opportunities in their introductory biology/laboratory courses.
As teachers we rarely see immediate payoff from our efforts, and it may be years later that we ever learn of any influence of our teachings. While I was writing this paper, I received an unsolicited email from one of my former IST students. I include the contents of his email below:

August 2009
I am currently printing out the Nature of Science activity we did in our IST course with the numbers and names on the cube for my Non majors Chem course I am teaching this fall. I thought of you and thought you would be pleased to know the effect of your efforts on now my full time job of teaching undergraduates science. I am excited and nervous all at the same time, as I attempt to do this vocation of teaching. I think I am afraid with three new courses this fall and 8 lectures to prep for a week, that I will lapse into a teaching style which just gets it done, rather than try to think and reflect on how best to teach the material. I remind myself that it will likely take me years to become a skilled educator. Thanks for helping me in that process. All the best, Sam Assistant Professor of Biochemistry-- University—USA
Table 2 Pre-Views of Inquiry and Evidence of Inquiry-based Features in Lesson Plans

<table>
<thead>
<tr>
<th>Name</th>
<th>Degree/Level</th>
<th>Beginning of course -inquiry-based teaching?</th>
<th>Lesson Topic/Concepts</th>
<th>End of Course (Statements in Lesson Plan related to Innovative Teaching Components)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dean</td>
<td>Chemical Biology (profiling proteins known as proteomics), 4th year</td>
<td>Do not know.</td>
<td>&quot;Proteomics&quot; designed for an undergraduate biochem course</td>
<td>The students will be able to design a gel-based comparative proteomics experiment, which involves proteome isolation, analysis and comparison…</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Discuss with their group mates their ideas …The students will be able to complete a pre-lab report explaining how they will perform the comparative proteomics experiment.</td>
</tr>
<tr>
<td>Kole</td>
<td>Electrical Engineering</td>
<td>A strategy aiming to arm students with their own internal motivation to discover and ask on their own, which is the best way to have students choose science as their own discipline.</td>
<td>Einstein's Special Theory of Relativity</td>
<td>Inquiry and student centered strategies'; Animations, thought experiments, historical experiments will provide a hook for students; Heavy emphasis on discussion - questions posed will be thought provoking for all, Students will question each other questioning and reflection, A class environment where everyone can bounce ideas off each other would enhance understanding greatly.</td>
</tr>
<tr>
<td>Jason</td>
<td>Electrical Engineering/Computer Science</td>
<td>(No response.) I'm concerned that I might not have the appropriate pre-requisites,</td>
<td>Introductory Algorithms</td>
<td>Driving Question</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>We all sort things in our daily lives: the mail, books, clothes in our closet. We all have our own, different methods of sorting things that we really like, because they work for us, they feel right. The same is true for computers: say you're trying to organize your MP3 collection alphabetically by artist. There are lots of different ways you can sort a set of data alphabetically, but which one do you choose • Students should understand the tradeoffs between computational time and memory usage in sorting algorithms (and begin to see applications to other algorithms).• Students should also understand how these characteristics change as implementation details change.</td>
</tr>
</tbody>
</table>

Implications for Further Research

The findings of this research suggest that, given opportunity, prospective college instructors can learn about and articulate reformed-based teaching approaches, and begin to think about using less teacher-directed, lecture-based modes towards more inquiry-based approaches. What we do not know is the extent to which college professors can sustain their intentions to, or are able to, design inquiry-based learning environments in their college classrooms. To what extent will these novice college instructors develop practical knowledge that will serve them and sustain them (Driel, v., Beijaard, & Verloop, 2001)? Needed are more studies exploring the enactment of inquiry-based teaching approaches in actual college classrooms, across the range of settings from large, highly competitive, research oriented universities to small teaching-focused colleges. Additionally, we need to understand the constraints to this kind of teaching, which may have no immediate payoff for an untenured science faculty member. Finally, we need to understand more about how to support new college professors, such as Sam, as he navigates the unchartered territory of innovative teaching.
References


Tobias, S. (1990). *They're not dumb, they're different; Stalking the second tier*. Tucson, AZ: Research Corporatio


PREPARING FUTURE SCIENCE FACULTY: EXPERIENCES IN A METHODS COURSE FOR COLLEGE TEACHING

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Abstract

How do we prepare the future science faculty to teach effectively? Science content knowledge and skills may be necessary, but they alone are insufficient. Emerging from the literature on teacher education, professional development, and reform in higher education, we have developed a methods course, Teaching and Learning in the College Science Classroom, geared toward preparing graduate students to effectively teach in the post-secondary setting. The course is modeled after those required for pre-service K-12 teachers, where the focus is on reflective practice and building science pedagogical knowledge and skills. The course targets graduate students from the science disciplines and from science education who will seek positions in academia with responsibilities in undergraduate science instruction. The course develops reflective practices through study of contemporary teaching and learning theory, concepts of nature of science and scientific inquiry, course and lesson development, and instructional and assessment strategies that promote active learning. Changes in students’ views about teaching and teaching practices were examined through student work, course evaluations, and interview.

The problem

Most of us who have taken undergraduate science courses have experienced, at least once, large lecture transmission-style teaching where we copiously copied notes or sat passively, listening to the teacher read slide after slide after slide. In “Talking About Leaving,” Seymour and Hewitt (1997) describe their comprehensive study of why undergraduates choose to remain in science, mathematics, or engineering [SME] related majors, or choose to leave those majors. Of the 335 students (switchers and non-switchers) in their sample, 83% stated “poor teaching” was a concern. For those who switched out of their major, 90% reported they thought the SME teaching was poor and 60% reported losing interest in SME. Clearly there is a need to examine undergraduate science teaching practices and prepare future science faculty to be more effective teachers. The purpose of this paper is to describe an intervention aimed at preparing future science faculty to effectively teach post-secondary science through promoting inquiry, active learning, and reflection.

Although there have been calls to reform undergraduate instruction for over 100 years (Pitkin, 1909), change is slow (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003; Henderson & Dancy, 2007; Seymour, 2001). Both personal and contextual factors contribute to faculty resistance to alter instructional style from didactic, transmission of information toward a constructivist style where students are active learners. Gess-Newsome et al. (2003) described the role of pedagogical and contextual dissatisfaction in fostering change. For change to happen the instructor must recognize a need to change. There must be dissonance between the teacher’s personal beliefs about science teaching and his/her practices of science teaching. This pedagogical dissatisfaction may then be resolved through change of practice to match beliefs. Interventions such as professional development, action research, and coursework may facilitate the change. The context of the current intervention is a graduate level course for future science faculty. The purpose of this paper is to (1) describe the course rationale and main activities that aim to generate dissatisfaction and resolution through reflective practices; and (2) describe reported impacts of the course on student views and teaching practices.
Context: The Methods Course

Considering the literature on teacher education, professional development, and reform in higher education, we developed a graduate-level course geared toward preparing the future science professoriate. *Teaching and Learning in the College Science Classroom* is a methods course, modeled after those required for pre-service K-12 teachers, where the focus is on building reform-based pedagogical knowledge, skills, and reflective practices (NRC, 1996, 2000). The course meets for 3 hours, once a week, for 15 weeks. The course targets graduate students from the science disciplines and from science education who will seek positions in academia with responsibilities in undergraduate science instruction. Currently, the course is a requirement for our doctoral students in biological sciences and in science education. Most of the students enrolled are also teaching assistants in their science department. Our Science Education doctoral program has a “College Science Teaching” track for students who aim to pursue teaching positions in science departments. These students take the Methods course twice, with additional course requirements the second time (Table 1).

The course focuses on reflection on and about teaching. Reflective practice is a key to building professional knowledge and continued self-improvement (Loughran, 2002; Schon, 1987). The course aims to develop reflective practices through study of contemporary teaching and learning theory; nature of science and scientific inquiry; course and lesson development, practice, and observation; and instructional and assessment strategies that promote active learning. Nature of science and scientific inquiry are explicitly addressed throughout the course. This is a practical application course where students practice designing, implementing, evaluating, and reflecting upon science instruction to promote critical thinking skills and scientific reasoning.

The syllabus explicitly states the objectives in Table 1. Each class session and assignment is designed to target at least one objective.

**Table 1. Course Objectives**

<table>
<thead>
<tr>
<th>Each student will:</th>
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<tbody>
<tr>
<td>- Develop skills of reflection necessary for continued improvement of teaching practices</td>
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<tr>
<td>- Develop an understanding of scientific inquiry and the nature of science and their relation to teaching science</td>
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<tr>
<td>- Develop an understanding of constructivism as a learning theory and teaching perspective</td>
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<tr>
<td>- Become familiar with current national education reforms associated with post-secondary science</td>
</tr>
<tr>
<td>- Describe various instructional strategies and rationale for use in the science classroom</td>
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<tr>
<td>- Develop skills in designing, implementing, evaluating, and reflecting upon science lessons to promote higher order and critical thinking skills</td>
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<tr>
<td>- Develop a course syllabus and full unit plans for an introductory science course</td>
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<tr>
<td>- Be aware of equity and diversity issues in science education</td>
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<tr>
<td>- Begin construction of a teaching portfolio</td>
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</table>

Doctoral students may elect to take the course twice. Second-times have additional requirements:

- Design and conduct an action research investigation to explore a problem or question drawn from their science teaching experience
- Complete a teaching portfolio

The first day of class I ask the students to describe their teaching and learning aspirations. I ask them, “What are your teaching career goals?” “What are three things you are looking forward to about teaching science?” “What are three things that concern you about teaching science?” and “What do you hope to gain from this course?” The first day also includes a self-assessment of views about nature of science and scientific inquiry. I use a version of the VLOS (Lederman, Abd-El-Khalick, & Bell, 2002) and VOSI (Schwartz, 2004) to help students begin the process of thinking about nature of science and scientific inquiry. For most of the students, this is the first time they have been challenged to formalize their ideas about what science is, what scientists do, and how these may relate to science.
teaching. Early class discussions focus on where these views originate and how the science classroom is a venue for developing ideas, attitudes, and aspirations about science.

During the first few weeks of class, students engage in inquiry and nature of science lessons, many of which have been described and shown effective (e.g. Lederman & Abd-El-Khalick, 1998; NAS, 1998; Schwartz, 2008). Students have readings, see video tapes, make class observations, and begin to write reflections. As they are introduced to concepts of nature of science and scientific inquiry, they consider how these concepts are manifest explicitly or implicitly in the science classroom. The themes of Nature of science and scientific inquiry emerge throughout the semester. Early in the semester students conduct their first of several classroom observations and describe how nature of science was portrayed during the class.

This first observation also requires students to begin thinking like a teacher, a perspective that is quite new to many of them. Many of the students, especially those who have little or no experience with education courses, tend to focus on what science is taught (e.g. content). They struggle to put themselves in the shoes of the teacher and focus on how the science is taught. Discussions and feedback during the first several weeks of class try to highlight the distinction and importance of the latter in becoming a reflective teacher.

Students experience a variety of instructional strategies during the semester, all with rationale for application in the college realm, and all with explicit attention to nature of science and inquiry. Students develop lesson plans (one for large lecture; one for laboratory), practice teaching, and implement many of the instructional and reflective strategies in their own undergraduate assignments as teaching assistants. They observe each others’ teaching, video tape and reflect upon their own teaching, share experiences, construct written reflections, and share their experiences and ideas. These common experiences help build their peer community. Table 2 lists the main course topics from the semester.

Table 2. Course topics

1. Understanding the goal
   - Self assessment: Views of nature of science, Views of nature of scientific inquiry, Views of good teaching, Personal experiences & goals
   - Goals for higher education and the need for reform
   - What is effective teaching?
2. Nature of Science and Scientific Inquiry
3. Looking at teaching: Conducting classroom observations; Why’s & How’s of reflection
4. Who are our students and how do they learn?
5. Active learning: What does it look like in the college classroom?
6. Equity and diversity
7. Inquiry as pedagogy: Levels of inquiry
8. Questioning strategies: turning teacher-centered to student-centered
9. Instructional strategies: Demonstration, Large lecture, Technology, Discussion, Laboratory
10. Instructional planning
11. Technology integration
12. Assessment strategies: Higher level objectives; Authentic assessments
13. The scholarship of teaching: Action research and Research on teaching and learning

Course Assignments

Course assignments aim to help students examine their views in a reflective way and to immediately apply what they are learning. Some of the major assignments are described here.
Develop a Teaching Philosophy

Good teaching involves personal reflection both on practice and position. During this course, students are required to examine their experiences and beliefs to develop a statement of personal teaching philosophy. They do this at the beginning of the semester. They then revisit their initial ideas and revise their statement at the end of the semester. Because most of the students come from a science background, this exercise is entirely new. They have not thought about what it means to teach or what learning looks like. As a class, we discuss what type of information should be in such a statement. At the end of the semester, students revisit their original statements and revise them according to how they feel their ideas have change.

Develop Reflection on Practice: Teaching Observations

These students have a wealth of experiences within college science classes from a student’s perspective. Understanding and developing reflective practice requires these students to shift perspectives away from the specific content. Like all pre-service teachers, they must learn how to examine the dynamics of teaching and learning. This is not an easy shift, especially for many of the content-focused students. To aid in this shift, the students conduct several observations of typical college science classes, their peers, and themselves. To begin, they choose a large-lecture style class being offered in their discipline (50+ students). They contact the faculty instructor and arrange to observe at least one session. They do the same for a small group or laboratory session in their discipline. For each, students write a 2-4 page reflection of their observations, including how the class demonstrated elements of effective teaching; what image of nature of science was portrayed; what might help to improve the lesson; and specific questions their observations raised concerning teaching in that setting.

Observing, reflecting upon, and discussing one’s own and peers’ teaching are important parts of learning to teach, as well as critical to building a collaborative environment for continued improvement. Through the semester, students conduct both peer and self observations/ reflections.

- **Peer Observations** (at least two) Meet with the peer and decide on a focus for the observation; conduct the observation (field notes; observation technique); write a reflection; meet with peer to discuss
- **Self Observations** (at least two): A peer videotapes the student teaching an undergraduate science course (most students hold a teaching assistantship); the student views the tape and critically reflects upon his/her own practice, identifying specific strong and weak points and making suggestions for improvement.

Plan, Practice, and Feedback

For many college instructors, planning for a lesson seems to involve little more than deciding upon the main topic for the day (e.g. cell structure/function) or an activity (e.g. identify cell parts; do the respiration experiment). Helping future teachers understand the concepts and practical application of such elements as ‘essential questions,’ objectives, and skillful questioning to engage students in meaningful inquiry and discourse requires modeling, guidance, practice, and feedback. Class sessions model these instructional styles and students then develop their own lesson plans. A requirement is that all lessons and lesson plans must explicitly address at least one objective for ‘nature of science’ or scientific inquiry in addition to other content objectives. The plans must reflect strategies for promoting active learning and higher order cognition. At least one lesson plan must integrate technology. Specifically, students:

- Develop two lesson plans related to concepts they would likely be teaching at some point in their future. They develop a lecture plan that reflects “active” learning, and a laboratory plan that reflects an inquiry-orientation.
- Develop/teach two lessons to peers. One of these is an individual teaching demonstration. The other is an inquiry laboratory lesson that they design and teach in teams of 3 or 4.

Course Project: Syllabus and Unit lesson plans and rationale

The course project requires students to apply themes from the semester to design an introductory course within their discipline. They can target majors or non-majors. The purpose of focusing on the introductory level is so that students attend to conceptual issues beyond their specific area of expertise. Sometime during their career, they will most likely be asked to teach such a course. Introductory courses are critical venues for attracting and retaining
students into STEM fields. One of my goals as the instructor is to enable these future faculty to step into a position with a syllabus and instructional plans that reflect reform-based teaching. Students (1) develop a course syllabus and (2) select one of the units from their syllabus to fully develop all instructional materials needed to teach those lessons. The whole unit must span at least five class sessions. Plans must include all assessments, such as homework assignments, quizzes and exams related to the unit. It is important for students to consider why they are choosing to teach a particular concept in the first place, and why they are choosing to teach the concept in a particular way. As part of the unit plan, students need to include a written “unit rationale” that explains why the concepts are important for the students in to learn, how the unit fits within the course, and why the chosen instructional and assessment approaches are appropriate for the concepts. Coinciding with the course focus on “reflection,” students also provide a written description of how they have implemented the themes of the Methods course through their course design and plans.

Impact of the Course on Student Views and Practices

Three types of data were examined over two semesters (23 students): student work, course evaluations, and a focus group interview. Data were examined qualitatively for themes related to course impact. Findings from review of each of these data sources are presented separately.

Student Work

Through both semesters, I kept notes and reflections about challenges I noted in student progress. I was able to track trends and developments over the semester through examining initial goals related to the course, teaching philosophies, lesson planning written reflections and teaching practices.

Initial Ideas

What are your teaching career goals? In the pre-course survey, the students indicated they were interested in learning more about teaching science, as they had goals of teaching at the college level. Regarding their teaching career goals, half the students focused their statement of teaching at the college level, “I want to teach physics in a community college.” The other half focused their statements on the learner, where they wanted to help students to learn science and become engaged with and excited about science: “I hope to be an inspiring teacher who encourages students to look around them and wonder.”

What are you looking forward to about teaching science? The majority of students (85%) were looking forward to generating excitement and interest amongst their students. Jenny said, “I want to excite students to want to learn more and more.” Some of the students want to be teacher educators and looked forward to getting their future students prepared to teach. Sean, a graduate student in science education said, “[I look forward to helping] my students develop confidence to teach their science subjects.” About 30% of the students suggested a transmission orientation to science teaching. Caleb, a graduate student in biology, stated, “I love just talking about science and enlightening someone or providing increased knowledge.” About 30% recognized they would continue to learn through the act of teaching, “[I look forward to learning from my students] and “learning through the experience [of teaching].” About half the students each semester were from science education, and most of these had been exposed to concepts of scientific inquiry and nature of science prior to taking the Methods course. 15% of the students, all from science education, mentioned looking forward to teaching science by inquiry or teaching about nature of science.

What concerns do you have about teaching science? Half the students expressed concerns of their own content knowledge. A biology student said, “There are vast levels of knowledge out there. What don’t I know?” Half also indicated concerns for recognizing student challenges. They wondered if they would be able to handle student misconceptions or boredom in the classroom. Joe stated, “I am not always knowing when the class is bored versus not comprehending.” Only a few students raised concerns over finding activities or appropriate lessons. One student explicitly stated he had a fear of “failure,” but he did not elaborate on what would constitute failure.

What do you hope to gain from this course? The majority of students (62%) stated they wanted to gain knowledge of teaching methods (general), where 38% specifically mentioned wanting to gain knowledge of methods to actively engage students. Susan’s interest in specific strategies is suggested in her comment, “[I hope to gain] anything I can do to improve my teaching methods and engage my students more directly to get them involved.” These statements were a positive indication that some of the graduate students were thinking about teaching in terms of the learner.
Receptive or/Resistant

For the most part students were very receptive to thinking about teaching and learning. Their pre-course survey indicates they all had teaching goals and thought they could gain something from the Methods course. However, the students were not equally receptive, at least not at first. Most resistance seemed to come from those students with the most teaching experience. In both semesters there were one or two students who had been pre-college teachers. These students provided valuable insights into teaching and learning, yet their experience may also be a barrier to their own professional development as a college science teacher. At first, these students struggled to see any differences between middle or secondary science contexts and the college science context. Further, their preparation for microteaching and lesson plans seemed substantially less than that of their peers who were newer to teaching. There were notable episodes of “Oops, I didn't practice that demonstration. It should have worked” or “I know what I would do in the lesson because I’ve taught it before. I just didn’t write it down in my plan.” Practice, feedback, and peer interactions highlighted pitfalls of poor planning. Most of the students experienced moments where they forgot to include something in their practice (or actual) teaching because they didn’t include it in their lesson plans. Viewing and reflecting upon their videotaped lessons, in addition to holding post-observation conferences with their peers, seemed to reduce their resistance. For the most part, these students came to value the need to plan and the need to reflect from the perspective of college science teaching.

Changes in Views and Practices

Student work such as teaching philosophies, reflections, and lesson plans were reviewed to track progress over the semester. These sources were also used as formative assessments that guided instructional decisions. For example, early on it was apparent that I needed to provide more guidance and modeling of reflection to help students move beyond more superficial classroom features, such as where the teacher walked, to more sophisticated pedagogical features such as levels of questions and use of student ideas. I tried to incorporate relevant discussions into my lesson plans to target the needs of the students during the semester. In essence, I made every effort to model the type of teaching practice I expected of the students. Table 3 presents notable trends identified from two semesters of teaching the course.

Table 3. Notable changes over the semester

<table>
<thead>
<tr>
<th>Task/Views</th>
<th>Initial perspectives and abilities</th>
<th>Changes noted through the semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Teaching Philosophy</td>
<td>First teaching philosophy statements tend to reflect a traditional didactic orientation where the main focus is content delivery.</td>
<td>Final teaching philosophies are more reflective of an inquiry, student-centered teaching orientation. Not all statements are consistent, suggesting some are still struggling to sort out their views. Reflections improve over the semester, yet some students struggle to provide rationale for their ideas. Videos of classroom episodes followed by class discussions seem to be most helpful in aiding students to become reflective.</td>
</tr>
<tr>
<td>• Reflections</td>
<td>First observation reflections tend to focus on content as opposed to pedagogy (“I think the teaching was good because he went over all the details of reflection and refraction.”). Reflections lack specific examples and suggestions with rationale.</td>
<td>Lesson plans improve substantially, but specific feedback for individual plans is crucial. Students show a marked improvement in planned questions for both lecture and laboratory settings.</td>
</tr>
<tr>
<td>• Lesson Plans</td>
<td>First lesson plans tend to reflect a didactic approach with too much information and unrealistic time estimates (e.g. 85 slides to deliver in a 50 minute class). Students do not plan questions, but assume they will remember to ask questions periodically and that their students will automatically give the desired response.</td>
<td>Students show improved understanding of and ability to adjust lessons to reflect higher inquiry levels. They can identify cookbook labs and suggest ways to increase inquiry levels. They show improved ability to identify appropriate nature of science elements within lessons. Yet, they still struggle to address nature of science and inquiry explicitly and reflectively.</td>
</tr>
<tr>
<td>• Conceptions of Inquiry teaching</td>
<td>Students have little to no concept of what scientific inquiry looks like in a classroom setting. They are unsure of how to help students actually think, as opposed to memorize and reiterate.</td>
<td></td>
</tr>
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</table>
Course Evaluations

Anonymous course evaluations provide evidence that the course was well received and considered beneficial. Student ratings averaged 4.4/5.0 for overall course and instructional quality. Through written comments, the students indicated the following elements were most beneficial: Creating the syllabus and lesson plans; Discussions with peers (in and out of class); Observing peers; Action research; Practice teaching, reflection, and feedback; Videotaping myself; Learning about nature of science and inquiry.

Focus Group Interview: Students’ Perceptions of Course Impact

Five months following the completion of the course, six former students participated in a one-hour focus group interview conducted by a graduate student in science education (also a former student). The purpose was to elicit student perceptions of how the course impacted their ideas of science and science teaching, how they may have been able to use what they gained from the course, any changes they have experienced in their teaching or teaching views since taking the course, if they feel the course was beneficial and what elements of the course had the most impact. The interviewer audio-taped and transcribed the interview, removing all identifying information. Interview transcripts were analyzed for related themes.

The main reported impact of the course was “raised awareness.” Most of the students had not thought about teaching, let alone about planning, reflection, or the scholarship of teaching. Students reported that discussions with peers, teaching observations, and practical application of planning and reflection were influential to raising their awareness of the possibilities of science instruction and what they need to continue to consider in their own teaching. The following are representative quotes from the interview that highlight student views.

Novelty of ideas

- “I understood science but did not necessarily know how to teach it…so like scientific inquiry, nature of science and… all those different things. I just never had thought about them before, let alone how to teach them.”

Reflection as a tool to improve

- “I mention observations and reflections as something that I had not considered much before. I used to think of just identifying mistakes and just leave it at that…but to kind of go ahead and learn through mistakes and research is…here we focus on reflection as tool to improve, which was very good to me.”
- “So [the course] really helped me to get an understanding of inquiry-based teaching and active learning and all the other things that go along with this course, and the new style of teaching in my case, as opposed to traditional. [the action research] allowed me to put together all those things and to then to actually put them into practice. There is nothing like the actual experience of using it in a classroom situation to see how it really impacts my teaching or a person’s teaching.”

Conceptions about their role as a teacher: Consider the students

- “Oh yeah I learned a lot from [the course]. I was coming in like a biology PhD because everything in class was my first time to come to know about. Like any teaching style, philosophy of teaching statement; I never have ever thought about it before. So this was very crucial for me. I had to stop thinking just as a scientist but also a teacher. So before the class, I was basically teaching to get money so that I may graduate. After [the class], the aim of my specific goal of teaching has changed. Well the money is there, but the primary focus is to teach the students.”
- “The misconception idea is very important…The science class that I teach I am wondering about trying to incorporate addressing misconceptions on a more regular basis, may be even a daily basis.”
- “I am trying to make my class more active when a student comes to me with a question. Instead of being a fountain of knowledge, I try to ask questions and kind of guide and demonstrate to them…”


Restrictions to TA's implementing innovative teaching strategies

As teaching assistants, the students rarely have autonomy to teach their classes their own way. They are required to follow someone else's guidelines and teach like all the others. This becomes problematic when others in the teaching group do not share the same teaching outlook. Despite the restrictions, some TA’s have been able to make small changes:

- "I am teaching with four to five other TAs, none of whom had taken this course. We are given a syllabus. We are giving evaluations, and what the students evaluate is little that we have control over in the lectures. [The course supervisors] wanted to kind of standardize so that each TA uses the same lecture. So that was kind of getting more restrictive. With those parameters I could develop some guided questions and make sure the students were comprehending. I would try to get some group activities like a group quiz at the end of the class where I challenge the students to get them to discuss with one another, but it is all within the confines of rather a cookbook style lab.”

Impact on faculty: Changing the teach as you were taught phenomenon

The second semester the course was offered, a faculty from biological sciences approached me to discuss ways she might improve her teaching. She was interested in learning more about the Methods course and wondered if she might audit. She was unhappy with her course evaluations and saw value in putting time and effort into her course planning. As most junior faculty in a science department, Jenny devoted a great amount of effort to her research. She decided to put more effort into her teaching by attending the Methods course and working on many of the assignments. Jenny and I met several times during the semester to discuss her teaching goals and plans. She was in the fourth year of her first tenure-track position. She taught one undergraduate biology course for majors and one graduate level course. She did not have any experience planning or teaching prior to joining the department. In her first year, she had been assigned to teach an undergraduate majors course. Her preparation was essentially to use an old syllabus and information from when she had taken a similar course, and develop her own course in a similar fashion. After several semesters of “teaching as she had been taught” she realized it wasn’t working for her. She was frustrated that many of her students were not doing well. She was frustrated that they were giving her poor teaching evaluations. She had pedagogical dissatisfaction (Gess-Newsome et al., 2003). She knew she needed to do something different but she didn’t know what that was.

Jenny attended the Methods class every week. She participated in discussions, class activities, and completed many of the class assignments along with graduate students from her own department. She was forthcoming with her frustrations and experiences in trying to develop and teach a course without previously thinking about what it takes to be a good teacher. She conducted teaching observations and reflections of several of the other students in the class. I observed her cell biology course and videotaped lessons for her so that she could conduct self reflections. She welcomed other students into her class to observe her teaching and discuss ways to improve.

At the start of the semester, Jenny’s lessons were primarily power point presentations. Her slides were numerous and heavy with text. She spent much of her lectures reading the slides, with little opportunity or invitation for student involvement. As the semester progressed, Jenny was able to incorporate several strategies for actively engaging her students in her lecture course (~60 students). She incorporated student group activities, discussion questions, and variation of media into her class. She drastically reduced the number of slides and information on the slides, and decided to provide students with skeleton notes that they could fill in during class. She embraced the concepts of “essential questions,” periodic review, and alignment. She began to notice students being more attentive in class, asking more questions, and performing better on exams.
Jenny commented that she wished she’d had the opportunity to consider teaching and course planning before she had her first faculty position. She felt that attending the Methods class and devoting time to improving her courses was important for her own professional development as well as her tenure prospects. Jenny reflected upon her experience:

- “I think every graduates student, and even faculty, should have an opportunity to think about what it takes to be a good teacher and what it takes to design a course. In my first position, I was just handed an old syllabus and told to teach my first classes. I had to do everything from scratch. I ended up teaching them just like they were taught to me. It was all I knew. But my evaluations were not very good, and so I thought there has to be a better way. I am really glad I sat in on this course. It has really helped me to see how to revise my classes to get students more involved. I have used the ideas of reducing the amount of text and information on power point slides, using a variety of media during class, chunking my lectures in 15 or 20 minute segments, incorporating planned discussion questions, and even doing group activities. I never did any of those before. I feel like a much better teacher. I see a real improvement in what the students are doing.”

**Implications**

This paper describes a unique experience specifically targeting future faculty. The reaction and reported impact of the Methods course on perceptions of teaching and learning in undergraduate science suggest the time is right and the need great for providing similar experiences in the preparation of science academicians. The case of Jenny suggests the need to include teacher education before the faculty are “thrown into the fire.” She was dissatisfied and took initiative to improve. The Methods class provided a supportive environment for her revise her personal practical theories of instructional practice (Gess-Newsome et al., 2003) and try new approaches. Yet how practical is this type of professional development for a junior faculty seeking tenure at a research 1 institution? Improving undergraduate science teaching requires changing the typical preparation of science faculty. The graduate students did not necessarily recognize their pedagogical dissatisfaction until they were introduced to a novel way of thinking about teaching college science. The notions of inquiry and reflection were new. They came to realize that faculty could create an engaging learning environment that promotes inquiry thinking, interest, and meaningful learning. They came to realize the value of reflection for continued improvement.

Pre-service college teachers, the future professoriate, need supportive opportunities to build knowledge and expertise in teaching, just as they do in research. A Methods course for future science faculty may be one way to foster systemic reform in science education. The extent to which they will continue to develop expertise with reform-based teaching is unknown. Future research is necessary to explore the extent to which the course experiences have lasting impact on the science graduate students’ teaching views and practices. Future research is needed to follow these graduate students into their teaching contexts during their post-doc and early faculty positions. Will they fall back to a teacher-centered verbose lecture style, or will they be able to implement their plans that promote inquiry and active learning? What barriers will they encounter? What supports will they need? How are the needs of future science faculty similar to and different from the needs of future K-12 teachers? These and other questions should be explored to promote high quality in undergraduate science teaching.

**References**


RELATIONSHIPS BETWEEN COGNITIVE AND EMOTIONAL ASPECTS OF UNIVERSITY SCIENCE TEACHING

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Abstract

The purpose of this paper is to identify and analyze relationships within and between the cognitive and emotional aspects of teaching subject matter at the university level. The model of pedagogical content knowledge (PCK) of Magnusson et al. (1999) was used to study the cognitive dimension. Emotional aspects included teachers’ attitudes towards the difficulty and importance of certain topics, and teachers’ feelings with respect to student learning. A sample of university professors (n=6) who taught quantum chemistry at the undergraduate level was interviewed. Data analysis combined a quantitative and qualitative methodology. Relationships were found between the cognitive subcomponents of the Magnusson model, between emotional aspects, and between cognitive and emotional aspects of teaching quantum chemistry.

Introduction

In research on science teaching, much attention has been paid to teachers’ knowledge and beliefs (Abell, 2007). However, most studies concerned primary and secondary teachers. Relatively little research has been done at the university level. Moreover, although it has been argued that emotions are at the heart of teaching (Hargreaves, 1998), there have been very few studies in the domain of science teaching that have taken the emotional dimension into account (Zembylas, 2004a, 2004b). The project reported in this paper concerned the teaching of quantum chemistry at the undergraduate level. Initially, the focus was on chemistry professors’ pedagogical content knowledge (PCK) of quantum chemistry, gradually we became more aware of the importance for these teachers of the emotional dimension of teaching quantum chemistry. Consequently, we broadened the scope of our study, seeking for relationships within and between the cognitive and emotional aspects of teaching quantum chemistry at the university level.

Rationale

In the science education community, one of the most studied PCK proposal was elaborated by Magnusson et al. (1999). These authors claim that PCK is “a teachers’ understanding of how to help students to understand one specific subject matter”. Magnusson et al. (1999) describe PCK as the knowledge that is acquired after a transformation from various sources of knowledge: subject matter knowledge, pedagogical knowledge and knowledge about the context. The combination of these three main sources leads to the formation of pedagogical content knowledge. According to these authors PCK has five components: 1) Orientation towards teaching science, 2) Knowledge of science curricula, 3) Knowledge of students’ understanding of science, 4) Knowledge of instructional strategies, 5) Knowledge of assessment of scientific literacy. In this proposal the last four components
are all interrelated with the first one. Although in these PCK components is included almost all knowledge that science teachers should have, Magnusson et al. (1999) do not include subject matter knowledge per se, that knowledge in which every teacher should be an expert, and as Gil (1991, p.72) said “a good knowledge of the subject must include: knowledge about the history and philosophy of the subject, knowledge of the teaching methodologies, knowledge of the relationships among science-technology-society, knowledge about recent proposals or discoveries and to have some knowledge of those subjects related”.

Many PCK researches have been focused on secondary school, high school and pre-service teachers, and only few of them have taken university professors as their object of study (Goodnough, 2006; Major and Palmer, 2006; Padilla et al., 2008). The necessity to study the pedagogical ideas and training of university professors was pointed out by Campanario (2002). He claimed that university teachers often have developed specific ideas and conceptions about how university teaching is, or should be. Mostly, these teachers do not have a pedagogical background, but they are primarily researchers, and as such, they are experts in the subject they teach. When they have to teach, they often do this in the same way in which they were taught.

In their paper about chemistry teachers’ knowledge base De Jong, Veal and Van Driel (2002) remarked the importance to develop chemistry teachers’ SMK and PCK “in an integrated manner” and this would be particularly important for university professors. Studies on teaching chemistry at the university level have focused on the following subjects: chemical demonstrations (Clermont, Borko & Krajcik, 1994), physical and organic chemistry (Treagust, Chittleborough and Mamiala, 2003), chemistry laboratory (Hofstein et al., 2003, 2004; Bond-Robinson, 2005), amount of substance (Padilla, 2004; Padilla et al., 2008), and chemical reaction (Reyes and Garritz, 2006). The present study will focus on the teaching of quantum chemistry at university level, because one of the authors uses to teach this subject in an introductory manner.

Research questions

In order to elucidate PCK about quantum chemistry from university teachers, initially we used the following research questions:

1. What is the content of the PCK subcomponents of experienced university teachers of quantum chemistry?
2. What kind of connections can be found between these PCK subcomponents?

Later an additional research question was added:

3. …(about emotional aspects)

Method

Sample

As we have said before the original main purpose of this research was to study the PCK of university teachers, specifically those who teach quantum chemistry at the Bachelor’s level. To do that, we contacted ten teachers from different universities in the Netherlands. Six of them answered positively. The six teachers, besides to have an expertise in the subject, have taught Quantum Chemistry at university level from 2 to 25 years. To preserve their anonymity we will use pseudonymous.

Procedure

We designed a set of questions related to basic concepts which are taught in quantum chemistry courses. These questions were related to components of the PCK model. Sample questions are:
1. What kind of ideas related to this concept do you think your students have before take this course?
2. What do you do to help your students to understand this concept?
3. When you make your planning what kind of strategies do you use to catch students’ interest?
4. What kind of strategies do you use to check students’ understandings of this concept?

The author interviewed each teacher individually, and the interviews (lasting from 45 minutes to one and a half hour) were recorded, transcribed and analyzed.

Analysis

To the analysis process was adopted a systematic procedure, which consisted of the following steps: First, the interviews were transcribed in full and the author read the transcripts repeatedly to get an overview of the interviews. Second, each interview was broken into different fragments (45 to 94). Fragments consisted of one or several lines that concerned the same issue or topic.

Next, to develop a coding scheme, we started with Magnusson’s model of PCK which consists of five components related to: orientations towards teaching science (A), teacher’s knowledge of science curriculum (B), teacher’s knowledge of students’ understanding of science (C), teacher’s knowledge of assessment in science (D), and teacher’s knowledge of instructional strategies (E). For the purpose of this study, each of these components was divided into other subcomponents that go from two to nine. In this case we considered only those subcomponents that are important to university level (In table 1 we show some examples of our code system).

While the data analysis has been done we realize that in the interviews appeared some paragraphs related to students attitudes towards the course, teachers’ feelings and attitudes towards the subject and students. So, we thought that it could be interesting to consider these sentences, which were considered as part of teachers’ emotional dimension, in our PCK analysis. So, we added three new “components” which are related to teachers’ attitudes and emotions. The first one is teachers’ attitude or feelings towards teaching (F), which is divided in two subcomponents: a) positive or negative attitude towards the subject (F1), which is related with appraisal emotional process, because depends on what kind of judgment teacher do in relation with the subject, b) positive or negative attitude towards the teaching-learning process (F2) (In table 1 is showed an small example of the code system), which is focused on teachers’ attitudes or emotions as happiness, frustration, hope or things that they wanted or not to do during the lecture and that are related with moods and feelings. Therefore, this subcomponent concerns teachers’ response tendency (Sutton et al., 2003) because we considered that depends on teachers’ perception about the teaching-learning process. The second emotional component is related to teachers’ perceptions or attitudes about students’ attitudes which is divided in two subcomponents: a) teachers’ perceptions about how to improve students self-learning, and how teachers stimulated this process (G1); b) teachers’ attitudes or feelings towards students’ attitude in relation to their own learning, and ways of learning (G2). These subcomponents are focused on what teachers think or do related to students’ attitude; it means that teachers make a judgment about students’ attitude or feelings and thus these subcomponents belong to appraisal processes (Sutton et al, 2003). Finally, we added one more component which is related to teachers’ attitude towards subject matter knowledge (SMK). Obviously, it is fundamental that teachers have a good knowledge of their subject, but teachers also have ideas about the importance of certain knowledge, what is fundamental and what is peripheral, what is confusing or attractive, and so on. We distinguished four subcomponents (H1-H4, see table 1) and we think that these fit in the subjective experience of emotions process (Sutton et al., 2003), because teachers’ feelings about SMK depend on how teachers perceive the SMK.

1 We have included a small introduction to emotions in table 1.
After several iterations, Table 1 was developed as our coding scheme. This table was developed by the first and one expert in the subject, by interpreting and discussing the content of selected interview fragments. In the next step, this code scheme was applied to the interview data. As a result, a matrix of N fragments per 26 codes (see Table 1) was developed. One first code analysis was made by the author, and a second one was made by a research assistant, who was not an expert in quantum chemistry, but who specializes on education research methodology. To each fragment 1 to 4 codes were assigned, and the codes were compared and discussed until agreement was reached by the author and the research assistant.

Table 1. Examples of the CODE system used to classify teachers’ sentences

<table>
<thead>
<tr>
<th>Orientation toward teaching Science (A)</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic Rigor</td>
<td>A2</td>
<td>Students are challenged with difficult problems and activities. Lab work and demonstrations to show the relationship between concepts and phenomena.</td>
</tr>
<tr>
<td>Didactic</td>
<td>A3</td>
<td>Teacher presents information through lecture or discussion, and questions directed.</td>
</tr>
<tr>
<td>Conceptual change</td>
<td>A4</td>
<td>Students are pressed for their views about the world and consider the adequacy of alternative explanations. Teacher facilitates discussion and debates necessary to establish valid knowledge.</td>
</tr>
</tbody>
</table>

Knowledge of Science Curriculum (B)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1. Teachers’ knowledge of goals and objectives</td>
<td>B1</td>
<td>Teachers’ ideas of students’ goals to learn that subject</td>
</tr>
<tr>
<td>B2. Teachers’ knowledge of specific curricular programs</td>
<td>B4</td>
<td>Knowledge of curriculum and materials related to the subject they teach and others related to this.</td>
</tr>
</tbody>
</table>

Knowledge of students’ understanding of science (C)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1. Knowledge of requirements for learning</td>
<td>C1</td>
<td>Prerequisite, abilities and skills to learn that concept and alternative conceptions</td>
</tr>
<tr>
<td>C2. Knowledge of areas of students difficulty</td>
<td>C3</td>
<td>Science concepts or topics that students find difficult to learn (abstract or lack any connection to students’ common experience) or non intuitive.</td>
</tr>
</tbody>
</table>

Knowledge of assessment in Science (D)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1. Knowledge of dimensions of Science learning to assess</td>
<td>D1</td>
<td>Those concepts that are important or not to assess</td>
</tr>
<tr>
<td>D2. Knowledge of methods of assessment</td>
<td>D2</td>
<td>What kind of strategies teachers use to assess students’ understanding or those that they consider are not so good.</td>
</tr>
</tbody>
</table>

Knowledge of instructional strategies (E)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1. knowledge of subject-specific strategies</td>
<td>E1</td>
<td>Strategies that are more general and could be used to teach almost any subject. (e.g. learning cycle)</td>
</tr>
<tr>
<td>E3. Topic specific activities (e.g. problems, demonstrations, simulations, or experiments)</td>
<td>E3</td>
<td></td>
</tr>
</tbody>
</table>

Teachers’ attitude toward teaching (F)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2. Positive or negative attitude or feelings towards teaching (response tendencies)</td>
<td>F2</td>
<td>Positive or negative feelings related to teaching-learning process. Besides this component is related to teacher believes associated with the difficulty of the knowledge and think that students have to get used to it</td>
</tr>
</tbody>
</table>

Teachers’ attitude towards students’ learning (G)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2. Teachers’ perceptions or attitudes about students’ attitudes</td>
<td>G2</td>
<td>Teachers’ attitudes or feelings about students’ perceptions or feelings towards their own learning.</td>
</tr>
</tbody>
</table>

Teachers’ attitude towards subject matter knowledge (H)

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1. Teachers’ ideas or perceptions related to the subject they are teaching. (subjective experiences)</td>
<td>H1</td>
<td>That knowledge that is important to know but it is not necessary to teach</td>
</tr>
<tr>
<td>H3. That knowledge that is classified as fundamental to understand this and other subject. ii. The difficulty to comprehend the physics behind mathematical equations</td>
<td>H3</td>
<td></td>
</tr>
</tbody>
</table>

2 Just some examples of each sub-component are shown in table 1.
In the following step, we computed the relative frequencies of each subcomponent per interview and the frequencies in which pairs of subcomponents appeared together in each interview. Next, the data matrix was introduced into PRINCALS\(^3\) to reduce the data and to identify relationships among subcomponents. It was decided to delete those subcomponents with low frequencies (< 3%), prior to the PRINCALS. From PRINCALS we got the information related to sub-components intertwine. This information was compared with the interview to verify the data got it.

**Results**

Since not all subcomponents were used by all teachers, we analyzed each case individually and then we made an overall analysis. However, due to lack of space, we will just show two complete cases, and some examples of the others. In table 2, we present the frequencies of different pairs of subcomponents for each teacher. These frequencies were obtained by counting how many times each pair of components appears in the same fragment of the interview.

Teacher Paul

Paul’s interview was the longest in time and information. We could obtain 94 fragments to be classified. The PRINCALS shows four important pairs of components. These are: A2-E3, F2-G2, G1-H1, B4-F1. All these pairs have a good correlation and fit very well in the whole solution, and have a good frequency of intertwine (see table 4). Each pair will be discussed individually. The first pair of components is F2-G2 is related with the emotional part of teaching. In this case the interview contained phrases like the following:

“I’m not being able to force them (G2) to be interested, but I try that the way I teach would be enthusiastic and lovely (F2)...”

**Table 2. Pairs related to each teacher and theirs frequencies of intertwine.**

| Relations between cognitive and emotional subcomponents are highlighted in bold. |
|---------------------------------|---|---|---|---|---|
| Paul | Philip | Iacobou | Matthew | Thomas |
| A2-E3 | 8 | A1-E3 | 4 | B3-C4 | 7 | **B2-F1** | 9 | C2-F1 | 4 |
| F2-G2 | 13 | F2-G2 | 7 | F2-G2 | 4 | F2-G2 | 12 | F2-G2 | 11 |
| B4-F1 | 12 | A2-E1 | 4 | B4-C4 | 5 | B4-C4 | 6 | E1-G1 | 3 |
| G1-H1 | 8 | B4-C1 | 5 | F1-H2 | 5 | A3-D2 | 5 | C1-C4 | 5 |
| B3-C1 | 4 | **C1-H3** | 4 | E3-H4 | 2 | B3-C1 | 4 | D1-D2 | 2 |
| A3-E1 | 6 | **B4-H3** | 4 | | | E2-E3 | 3 |
| D2-E3 | 4 | | | | | |

This sentence is a clear example of these two subcomponents. The first part represents G2, because Paul is talking about students’ interest during the lecture. With this idea Paul could have expressed that students’ interest on

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\(^3\) The PRINCALS methodology was used to explore the relationship among different subcomponents to each teacher. PRINCALS is essentially the same as Principal Components Analysis in that it allows calculating loadings for variables as well as scores for individual objects or persons, both with respect to the same dimensions. (Gifi, 1985, 1990). All statistical analyses were performed using SPSS software, version 14.1 [Note that in this version, PRINCALS is part of the optimal scaling techniques as ‘Categorical Principal Components (CatPCA)’; see also SPSS Inc., 1990: chap. 8].
subject depends not just on students’ attitude but even in the way he use to teach the subject and his own attitude in
the lecture. Besides, this is a clear example of the emotional dimension of teaching (F2), because he tries to be more
‘enthusiastic and lovely’ with his students. The second pair of subcomponents is B4-F1; this pair relates the teacher’s
knowledge about curriculum and materials, to the teacher’s feelings about the subject. This is the first pair which
related cognitive and emotional dimensions of teaching. In this case, this pair has a good fit, good correlation and
good frequency, which could mean that to Paul, this combination, is quite important for his teaching. In the next
quote, Paul shows how important it is to him to make cross references through the whole course to enable students
to build their knowledge:

“I cross references to back (B4) all to the first lecture and I try to do that all the time. That is what I do
during the lecture to try to have the key point on my red line in mind; I try to cross references back because it is a
pretty efficient way of building knowledge (F1)”

Another pair of subcomponents is A2-E3, we think that the relationship between these two subcomponents
is quite clearly illustrated in the following fragment:

“…the combination of direct interaction with students, and providing them challenging exercises (A2, E3)
and checking if they have understood the key concepts…”

The fourth important pair is G1-H1. In the following example, Paul is talking about the historical evolution
of quantum mechanics. He comments that although this is an important topic, he could not spend too much time
on it and left students to read about it if they are interested.

“I leave them to their responsibility to do additional reading (G1), even in a textbook which I provide them
or I left them to use other mediums. I try to make a small, but important historical moment to give a short account
of it (H1) and then I just tell them go and read about your self if you are interested… We don’t have time to do all
these steps in history, to follow the evolution, because I could do that and I beloved to do that, but we do not have
enough time.”

One pair of components that was also interesting to analyze, although it does not have a good correlation and
a good fit in the PRINCALS results, is A3-E1. In the following paragraph Paul is explaining how he is used to
introduce the wave-particle duality idea:

“I try to explain of what a particle is, and then I spend some time on the waves and explain all we know
about the diffraction of waves (A3) to deduced this experiment (double slit experiment). Then I focused in a couple
of things that, ok you can have an interference so they also interact with each other in a certain way (E1)”

The last pair that we will analyze from this interview do not have a good correlation or frequency, but has a
good fit in the whole solution, this is: B3-C1. This pair implies that the previous curriculum is quite related to those
ideas that could be useful as a learning tools to build the framework knowledge, but at the same time could be an
obstacle to get a good learning process:

“Some (students) have mini term solar system in mind (C1). I think that it is what basically they have from
high school (B3). If they have any model atom, it is the nucleus as a sun with electrons as a planets running around
in orbits (C1)”
Summary

Teacher Paul has four important relationships among the subcomponents. Three of them are close related with the affective dimension of teaching quantum chemistry. In the most relevant pair of subcomponents, Paul relates his own feelings towards the teaching process with the students’ attitude; the second shows the relation between Paul’s orientation towards teaching, and the kind of strategies that he uses to choose.

Teacher Philip

In the case of teacher Philip his interview was classified in 72 fragments that were analyzed in a qualitative way and the data matrix was introduced in the PRINCALS program, from where we got the pairs of subcomponents that have a good correlation and fit well in the whole solution, we found basically the following: A2-E1, G2-F2, A2-E3, B4-C1 with the frequency showed in table 2. Starting with F2-G2 pair that appears to be important for all teachers interviewed. In this case the kind of phrase that we found is:

“I hope to transmit the enthusiasm with which I look at quantum mechanics (F2) as a fundamental theory to understand nature and […] I hopefully try (F2) to transmit this enthusiasm for the subject. I think is friendly when the atmosphere can help and also stimulating as much as possible the dialogue with students (G2).”

Another interesting combination of subcomponents is A2-E3, which appears in Paul’s interview as well. We can understand why these subcomponents fit together, because A2 reflects a way of teaching focused on problem solving and lab work, and E3 reflects the topic strategies using principally problems, exercises, simulations, etc., and this relationship is reflected on the interview as follows:

“They (students) have to show, in the blackboard, to solve problems (E3), so every one can really contribute to this practical session (A2), not just with the teacher in front of and solving the problem for them”

Another relationship is the A2-E1 which shows that lab work or to solve problems and activities could be used as general teaching strategies, as we can see in the sentence below where teacher is talking about these two components:

“I think that at very basic levels one needs to combine the traditional theoretical lecture also with computer lab, exercises (A2)… the combination with visualization and computer lab can be a very positive strategy (E1) for interest of them”

A final quite interesting pair is that formed by B4-C1 which has a perfect correlation and a perfect fit. B4 shows the teacher’s knowledge about curriculum and materials, and C1 shows teachers’ knowledge about students’ prerequisite, abilities and alternative conceptions, as in the next paragraph is showed that teacher thinks that students need a good level of mathematics as a prerequisite to develop some skills in the subject.

“I think mathematics should be teaching in a good level at the very beginning in the first year (B4) in order to prepare the student also to deal with differential equations, imaginary objects, matrices (C1)”

Summary

If we wanted to draw a teacher’s profile of Philip, we could say that this profile may depend on three main pairs of subcomponents. The first one is the teaching orientation and teacher’s strategy; the second one is teachers’ feelings to his subject and his perception towards students’ attitude; and the third one is his knowledge about curriculum and how this influences the skills, abilities and preconceptions of students.
Discussion

In the present research we were initially focused on the study of the relations among PCK subcomponents. However, we had to acknowledge the importance of the emotional dimension of teaching subject matter (i.e. quantum chemistry) and thus also included emotional aspects into our study. So, it is interesting to notice that there is one pair of subcomponents which appears to be important for all teachers. This is F2-G2, which shows the relationship between two affective subcomponents. We think that this is interesting because it shows that these teachers are interested not just in the subject, but in their own attitude towards their teaching and the perception that they have about students' attitude, which seems quite important for their performance as a teacher. Iacobous gave us a clear example of these intertwined subcomponents:

“If I notice that students get interested, I become much better as a teacher; because I like that and I start to talk more about other things. If students demonstrate how bored they are, then also I become worse as teacher, because I start to stick just to the lecture notes and just tell them what they need to know and I feel less happy than when the audience was receptive…”

It is clear that even in subjects as difficult as quantum chemistry at university level, the students’ attitude could have a big influence on teachers’ way of teaching, and on teachers’ attitude towards the subject and towards students. For example, it is interesting to notice how Iacobous is worried about students’ attitude and how his own attitude changes when he has a receptive audience or not, this process is clearly a response tendency. At a more general level, it is noteworthy that attitudes and emotions appear to be quite important for these university teachers. Many researchers have reported that the emotions of elementary or secondary teachers are influenced by the context (family parents, school authorities, students behavior, etc.; see Hargreaves, 1998; Zembylas, 2003; Zembylas, 2004a; van Veen et al., 2005; Pekrun, 2006; Ainley, 2006; Meyer and Turner, 2006; Kelchtermans, 2007); however there is nothing reported about university teachers.

In addition to this relationship between affective subcomponents, we found two important cognitive relationships. These are among the orientation toward teaching and instructional strategies (A-E); and knowledge of curriculum and knowledge of students understanding (B-C). The first one, A-E, appears in two of the five interviews, and we have said that this relation would be quite natural, because, generally speaking, the strategies used to make students learn a specific idea or concept, would normally depend on a teachers’ orientation towards teaching. The second pair appears in four of the five interviews, and shows the relationship among teachers’ knowledge of curriculum and their knowledge of students understanding. Again, it seems plausible that teachers need to have some knowledge of what kind of concepts have previously been taught to students to comprehend much better students’ understanding before and after they take a certain course. We also noticed that these two cognitive components (B-C) are in three of the interviews related with one affective component, that is, teachers’ attitude towards teaching, specifically with positive or negative attitude towards their subject (F1). These relationships are presented in three of the five interviews, which we think is quite comprehensible because what a teacher wants to teach, or what he thinks should be taught, could easily depend on his own knowledge of the curriculum and students’ understanding.

Finally we found cognitive-affective relationships. In particular, these are between teachers’ perceptions related to the subject (H) and three cognitive components: knowledge of curriculum (B); knowledge of students’ understanding (C); and knowledge of instructional strategies (E). Teachers’ perceptions of the subject requires from the teacher a deep knowledge of the subject, per se, but at the same time a very good knowledge about the instructional strategies, the curriculum and students’ understanding. This means that teachers' moods and emotions about the subject often have a relationship with their (cognitive) ideas about the same subject, related to the curriculum, students’ understanding and teaching strategies.
Conclusions

This research has shown how the relationships among the cognitive and the emotional dimensions of teaching subject matter are, besides showing those relationships among subcomponents from different cognitive components. Despite we found some interesting relationships, we could said that the results presented here are not conclusive to say that the emotional dimension of teaching should be part of PCK, because our interview questions were not focused on both dimensions, just in the cognitive one. Nevertheless, we think that emotional dimension could be part or not of PCK but it should be part of the process of teaching, where teachers and their emotions have an important role. This dimension could make teachers to choose one kind of orientations, strategies, evaluations, etc. or another. Using Magnusson model as a starting point to our study, we have found teachers’ emotions are clearly related to their PCK and SMK. Consequently, we have modified the model from Magnusson et al. (1999) according to our findings, putting emotions on the top of a tetrahedron, which could influence subject matter knowledge, pedagogical content knowledge, pedagogical knowledge and knowledge and beliefs about context (see figure 1). We believe that it is necessary to develop specific research on this subject and try to show if the emotional dimension would be part of the PCK or it is just a kind of influence that teachers of any subject and level have to take into account when they are teaching.

![Figure 1. Model of relationships among the domains of teacher knowledge. Figure modified from Magnusson et al. (1999, pp.98)](image_url)

References


Contemporary Science Education Research:
TEACHING


Abstract

Many factors have been recognised as possible explanations of why teachers in higher education teach the way they do. Teaching intentions are additional explanatory factors for differences in teaching, which are especially of interest, because intentions initiate teachers’ actions. In this study, we examined in what ways specific teachers’ intentions regarding the integration of research in teaching are related to students’ perceptions of the learning environments. Interviews were held with university science teachers, and a questionnaire was presented to their students. The results show that teachers’ intentions related to tangible elements, such as the use of academics’ own research during the courses, are relatively more congruent with students’ perceptions than intangible elements. The results indicate that if students are to perceive and appreciate the intangible elements of research, academics need to become more aware of these elements and to take more care in drawing students’ attention to these intangible elements.

Introduction

Many factors influence the way teachers at university teach their courses. In research into teaching in higher education, much attention has been given to factors such as conceptions of teaching and learning (Kember 1997; Pajares, 1992), orientations towards teaching (Kember, 1997; Samuelowicz & Bain, 2001), and approaches to teaching (Stes, Gijbels, Van Petegem, 2008; Prosser, Trigwell, & Taylor, 1994). In a study among university teachers, Martin, Prosser, Trigwell, Ramsden and Benjamin (2002) discussed a critical issue in why teachers teach differently, namely, the differences in their goals and objectives for teaching and learning in their courses. According to Norton, Richardson, Hartley, Newstead, and Mayes (2005), teachers’ intentions reflect a compromise between teachers’ conceptions of teaching and their academic and social contexts. Many research findings on conceptions of teaching and learning show an ambiguous relationship between conceptions and teaching practice (Murray & MacDonald, 1997; Samuelowicz & Bain, 2001); others show a strong congruence between teachers’ intentions and their teaching practice when the context of teaching is clearly defined (Martin et al., 2002; Norton et al., 2005). Teachers’ intentions can give us more insight into the relationships between teachers’ cognitions and teaching practice. In this study, we considered university teachers’ intentions regarding the nexus between research and teaching in their courses.

Intangible elements in the research-teaching nexus

Neumann (1994) distinguished between the ‘tangible nexus’ and the ‘intangible nexus’ in the integration of research and teaching at universities. In the tangible nexus, the clearly visible, explicit forms of integration of research and teaching are categorised, such as teaching ‘research practicals’. In the intangible nexus, the more tacit, not directly observable forms of integration of research and teaching are grouped, such as creating an inquisitive research climate, fostering an innovative atmosphere, or stimulating the development of students’ research dispositions. Intangible elements have often been denoted by teachers and by educational researchers as relevant elements of learning to do research, but few researchers (McLean & Barker, 2004; Elen, Lindholm-Ylänne, & Clement, 2007; Van der Rijst, 2009) have addressed the relation between these intangible elements of the research-teaching nexus and student experiences of courses.
Modes of integration of disciplinary research into teaching

Healey (2005) suggest that the possibilities of integrating research in teaching can be described according to two dimensions: (1) running from emphasis on research products to emphasis on research process, and (2) running from students as audience to students as participants in research activities. Figure 1 shows the four quadrants, in which the vertical axis depicts the student role, and the horizontal axis shows on which research aspect the emphasis is put in a course. Healey (2005) labelled the two bottom quadrants of this model as 'research-led' and 'research-oriented'. In these two modes, students are perceived as an audience in research activities, in the sense that they do not directly contribute to the development of scientific knowledge. The 'research-led' and 'research-oriented' modes can be discerned in the difference between emphasizing research products and emphasizing the research process. In the 'research-tutored' and 'research-based' modes, students participate in research while focusing on the development of new knowledge in the discipline. This heuristic model provides us with a tool to broadly understand the main orientation towards the nexus of research and teaching in the courses. In this study we considered the four modes as qualitatively distinct ways to understand the emphasis put on the integration of research into teaching during the courses.

Figure 1. The four modes of the research-teaching nexus (cf. Healey, 2005)

Students’ perceptions of the research intensiveness of learning environments

Several studies into the quality of student evaluations of learning environments show that students’ perceptions are a valid and reliable source of data about teachers and teaching (Marsh, Rowe, & Martin, 2002). Marsh and colleagues (2002) conclude that student evaluations of research environments are reliable and stable, and that, therefore, students’ perceptions of learning environments are an effective method for gathering data about characteristics of learning environments. Additionally, how students perceive the learning environment largely determines the final effect of a course. For example, when a student perceives an assignment as irrelevant, it is likely that this student does not exploit the full learning opportunity. In an overview of research into students’ perceptions of learning environments in which a strong integration exists between research and teaching, Jenkins, Blackman, Lindsay, & Paton-Saltzberg (1998) show that students are more motivated when they encounter staff research at the institute at an early stage in their studies. Students experience courses as up to date and intellectually stimulating when teachers bring into play elements of their own research during their courses. According to the students, teachers become more enthusiastic when bringing up their own studies. The credibility of the staff and the institute increases when teachers have research responsibilities as well (Jenkins et al., 1998). Furthermore, students perceive a positive relationship between doing research projects and their learning (Turner et al., 2008). Finally, students
appreciate being socially and intellectually involved in a research group (Healey, 2005). Robertson and Blackler (2006) showed in an interview study that students in a research-intensive learning environment experienced ‘pride’, and were motivated by the enthusiasm of their teachers. Students are intellectually challenged by close involvement with research related activities. Turner and colleagues (2008) summarised the main findings of studies into students’ perceptions of the relevance of research for their learning. The advantages of a close connection between research and teaching, according to the students, are the enthusiasm of the teachers, the credibility of the staff, and the stimulus of being taught by a ‘well-known’ scientist. Furthermore, students experience that being actively involved in research activities increases their development of skills and their awareness of the research process. An important disadvantage of the involvement of teachers in research activities was the decline in availability of the staff. Additionally, when students are only partially involved in the research projects of their teachers, they do not always develop a sense of ownership of the project (Turner et al., 2008). Thus, research-intensive learning environments have advantages for student learning, but they also have some disadvantages.

Research question

The aim of this study was to identify associations between teachers’ intentions related to the research-teaching nexus and the students’ perceptions of the research intensiveness of the learning environments. The rationale behind this aim was to gain a greater understanding of the associations between teachers’ intentions which are put into practice and students’ perceptions. We considered teachers’ intentions regarding the emphasis on research in their courses and were interested in teachers’ intentions regarding both tangible and intangible elements of the research-teaching nexus. Therefore, the central question in this study was which associations can be identified between teachers’ intentions and students’ perceptions of the research intensiveness of university science courses?

Method

Sample

The participants were university science teachers (n=11) and their students (n=104) from a middle-large continental research university. Teaching staff with a research task as well as involvement in courses with a research component were asked to participate. The participating teachers volunteered to contribute to this study. The positions of the teachers varied from assistant to full professor, and represented six sub-disciplines within the natural sciences and mathematics, namely, astrophysics, biology, chemistry, computer science, mathematics, and physics (see Table 1). The term course was used in this study to indicate a curricular unit for which students get a certain number of credits, such as a series of lectures, practicals, or group-work sessions. The contents of the courses reported in this study were related to research in very diverse ways. Some courses were directly related to doing research, such as research practicals or research internship; others were more focused on listening to researchers, such as lectures from visiting professors or seminars about current research topics. The amount of time students were supposed to invest in each course varied between 28 hours and 196 hours of study load.

Procedure

During fall and winter 2007, the courses of the participating teachers were followed as part of a larger project which was focused on the research-teaching nexus in the sciences. Before the courses started, the participating teachers were interviewed about their intentions for the particular courses. During the last meetings of the courses, students were asked to complete a questionnaire about the research intensiveness of the learning environment (Van der Rijst, Visser-Wijnveen, Verstelle, & Van Driel, 2009). In total 69% (104) of the students who followed the courses completed the questionnaire. The response rates of individual courses varied between .25 and 1.00. Table 1 depicts the educational institutes, the method of instruction, and the response rates of the questionnaire per course.
Table 1. Background information of courses and response to the questionnaire

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Educational institutes</th>
<th>Year of study (bachelor's phase)</th>
<th>Method of instruction</th>
<th>Absolute response (response rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Adam</td>
<td>Astrophysics</td>
<td>2</td>
<td>Seminar</td>
<td>9 (.75)</td>
</tr>
<tr>
<td>Dr. Nathan</td>
<td>Astrophysics</td>
<td>1</td>
<td>Practical</td>
<td>18 (.90)</td>
</tr>
<tr>
<td>Dr. Tanya</td>
<td>Biology</td>
<td>2</td>
<td>Lecture</td>
<td>2 (.25)</td>
</tr>
<tr>
<td>Dr. Susan</td>
<td>Biology</td>
<td>1</td>
<td>Practical</td>
<td>10 (1.00)</td>
</tr>
<tr>
<td>Dr. Simon</td>
<td>Chemistry</td>
<td>1</td>
<td>Practical</td>
<td>2 (.33)</td>
</tr>
<tr>
<td>Dr. Paul</td>
<td>Chemistry</td>
<td>2</td>
<td>Practical</td>
<td>2 (1.00)</td>
</tr>
<tr>
<td>Dr. Edward</td>
<td>Chemistry</td>
<td>2</td>
<td>Practical</td>
<td>3 (1.00)</td>
</tr>
<tr>
<td>Dr. Charles</td>
<td>Computer Science</td>
<td>2</td>
<td>Seminar</td>
<td>8 (.53)</td>
</tr>
<tr>
<td>Dr. Howard</td>
<td>Computer Science</td>
<td>1</td>
<td>Seminar</td>
<td>39 (.87)</td>
</tr>
<tr>
<td>Dr. Carlos</td>
<td>Mathematics</td>
<td>3</td>
<td>Lecture</td>
<td>3 (.38)</td>
</tr>
<tr>
<td>Dr. Eliot</td>
<td>Physics</td>
<td>1</td>
<td>Lecture</td>
<td>8 (.53)</td>
</tr>
</tbody>
</table>

Interview about teachers’ intentions

The aim of the pre-course semi-structured interviews with the participating teachers was to retrieve their intentions before teaching the courses. The interviews comprised two structured questions, which were used to guide the conversation between interviewer and interviewee. The teachers were given multiple opportunities to raise matters which they considered to be important, and were asked to explain issues which were unclear to the interviewer or to give a clearer explanation of the rationale behind a statement. Two questions were asked about general goals and objectives for the course. The teachers were asked, first, to give a general explanation of the course (‘Can you give a general description of the course?’) and, second, to explain more specifically what they aimed to achieve during the course and how (‘Explain what you intend to achieve during the course and how you intend to achieve that’). In the responses during this interview, both tangible and intangible elements of teachers’ intentions were present. Teachers’ intended modes of the research-teaching nexus and their intentions to arrange research were considered tangible elements of the nexus, while, for example, support of students’ research dispositions during the courses was considered an intangible element.

Student questionnaire on research intensiveness of learning environments

In order to measure students’ perceptions of the learning environments, we used a previously developed questionnaire on the research intensiveness of learning environments (Van der Rijst et al., 2009). Three sources can be distinguished as the origins of the items in this questionnaire. First, the heuristic model of Healey (2005) about modes of the research-teaching nexus was used to find indications of tangible elements of the research-teaching nexus. Second, from the Postgraduate Research Evaluation Questionnaire (Marsh et al., 2002), items which focused on intangible elements of the nexus and research facilities, such as infrastructural needs or availability of staff, were retrieved. Third, items from the questionnaire of Verburgh and Elen (2006) about the research-teaching nexus were used to inform items in the student questionnaire about both tangible and intangible elements. The questionnaire used in this study consisted of three parts related to both intangible and tangible aspects of research in university courses. Part A of the questionnaire included the tangible attention paid to research during the course; it consisted of four scales, ‘becoming acquainted with recent research’, ‘participating in research’, ‘attentiveness to doing research’, and ‘using research of teacher’. Part B contained three scales about intangible research elements: whether students perceived themselves to be involved in the research community, whether their motivation for research had increased, and whether the development of their scientific research disposition had been stimulated. Part C, a single scale, covered the ancillary facilities, such as the availability of supervision, the quality of infrastructural elements, and the clarity of learning goals. Students were asked to score the items according to how relevant they thought the
statement was to the course. The five-point Likert scale ran from ‘almost never’ (1), through ‘hardly ever’ (2), ‘sometimes’ (3), and ‘reasonably often’ (4), to ‘almost always’ (5). For every scale, Cronbach’s alpha, means, and standard deviations were calculated for the present sample of science students (n=104) of the participating teachers. Reliabilities of the scales, measured using Cronbach’s alpha, varied between .82 and .95. Table 2 shows the eight scales from the questionnaire with reliabilities and illustrative example items.

Table 2. Scales of the student questionnaire with Cronbach’s alphas and exemplary items

<table>
<thead>
<tr>
<th>Scale</th>
<th>Alpha</th>
<th>Exemplary item</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 – Attentiveness to doing research (11 items) concerns the extent to which research was addressed during the course according to the students.</td>
<td>.95</td>
<td>During this course clear relationships were drawn between research and teaching content.</td>
</tr>
<tr>
<td>A2 – Becoming acquainted with recent research (5 items) concerns the amount of attention for recent research problems and results.</td>
<td>.89</td>
<td>During this course my awareness grew about the problems researchers struggle with at this moment.</td>
</tr>
<tr>
<td>A3 – Participating in research (5 items) concerns the extent to which students were involved in and/or contributed to research.</td>
<td>.90</td>
<td>During this course we searched for answers to as yet unresolved scientific questions.</td>
</tr>
<tr>
<td>A4 – Using research of teacher (4 items) concerns the amount of attention given to research activities of the particular teacher.</td>
<td>.91</td>
<td>During this course I got acquainted with the research of my teacher(s).</td>
</tr>
<tr>
<td>B1 – Stimulating a scientific research disposition (7 items) concerns the extent to which students were stimulated to develop a critical, scientific research disposition.</td>
<td>.86</td>
<td>During this course the teacher(s) urged us to ask critical questions about our work.</td>
</tr>
<tr>
<td>B2 – Integration in a research community (3 items) describes to what extent students were socially engaged in the research environment and appreciated the research climate of the educational institute.</td>
<td>.82</td>
<td>During this course I had opportunities for social interaction with researchers of the institute.</td>
</tr>
<tr>
<td>B3 – Motivation for research activities (3 items) concerns the extent to which students were stimulated to develop academically.</td>
<td>.85</td>
<td>During this course I felt stimulated to engage in further study in this research domain.</td>
</tr>
<tr>
<td>C – Quality of learning environment (10 items) describes the overall student satisfaction with the quality of the course, concerning issues such as availability of supervision and quality of ancillary facilities.</td>
<td>.90</td>
<td>During this course the teacher(s) taught me in an adequate way.</td>
</tr>
</tbody>
</table>

Analysis

The analysis of the interview data resembled classic content analysis (Ryan & Bernard, 2000, p. 785), in the sense that we worked with pre-developed categories to code the data. Four phases can be distinguished in the analysis procedure. The first phase consisted of the development of a codebook. The categories used to code the data originated from two sources. (1) The scales of the questionnaire about the research intensiveness of learning environments were used to identify teachers’ intentions regarding the emphasis on research in their courses, in fragments of the responses to the first two questions of the interview. (2) The four modes of the research-teaching nexus (Healey, 2005) were used to categorise how research was integrated in course activities. During the second phase, the interview questions were coded using ATLAS-ti as an electronic tool for qualitative analysis (Muhr, 1997). The transcripts of interview questions 1 and 2 were analysed using the part of the code book about the scales of the questionnaire, while interview questions 3 and 4 were coded using the part of the codebook about the aspects of research dispositions. The complete transcript was coded to retrieve the mode of the research-teaching nexus. During the third phase of the analysis procedure, a qualitative data analysis matrix was composed with the teachers on the rows and average students’ perceptions scores in the columns (cf. Table 3). In this matrix, those scales which were explicitly identified as intended in a course were highlighted, to identify congruency between teachers’ intentions and students’ perceptions. If an element was explicitly mentioned as intended in the course, and students rated that particular element high, congruence was assumed between teachers’ intentions and students’ perceptions. Similarly, if an element was explicitly mentioned as not intended in a course and students rated that particular element low, congruence was also assumed between teachers’ intentions and students’ perceptions. When the teacher did not mention an element, no assumption was made about intentions for the course concerning this element. This means that congruency could be determined only for those elements which were explicitly referred to during the interview. Congruency was assumed with students’ perceptions larger than 3.50 for intended elements,
and smaller than 2.50 for elements which were not explicitly part of teachers' intentions. Teachers who taught courses with similar modes of the nexus were clustered into groups to enable consideration of similarities between intentions to stimulate the development of research dispositions. In the fourth phase, teachers’ intentions regarding the emphasis on research in their courses, and their intentions regarding the development of aspects of students’ research dispositions, were combined with the mode of the nexus and with students’ perceptions of the research intensiveness of the courses elicited from the questionnaire in a narrative way. These narrative descriptions were composed by first reading the transcript, and then listing all codes and inferring the teachers’ intentions. Each course was characterised by one of the four modes of the research-teaching nexus. The scale averages of the students’ perceptions per teacher were added to the narrative descriptions to support a qualitative visual examination of correspondence between the variables. The overall means of all students per scale were calculated using the complete dataset, neglecting the nesting of students in classes. Finally, the information from the narratives, teachers’ intentions, students’ perceptions, and modes of the nexus were all combined in Table 3.

Results

Teachers’ intentions regarding their courses were described in a narrative format. The descriptions were clustered in groups according to mode of the research-teaching nexus. The descriptions are presented below, with fragments in italics for those codes which are characteristic of teachers’ intentions identified in the interviews. The scale averages of students’ perceptions per teacher were added to the narratives and can be found in Table 3.

Descriptions of teachers who taught courses with a research-led mode

In a course with a research-led mode of the nexus, the emphasis is put on research products, such as the understanding of theories or models. Students are ‘observers’ involved in scientific research activities, such as in listening to a lecture by a researcher, or observing a simulation of an experiment.

Dr. Carlos’s intentions for the course were mostly content-focused. The central issue in his lecture-type course was the transmission of understanding of the ‘flavour’ of mathematical argumentations. According to Dr. Carlos, this issue is the most relevant, and an important research disposition for research in that discipline. This course consisted of lectures in which Dr. Carlos conveyed and explained some mathematical argumentations relevant to the course theme. At the end of the course, each student was asked to give a presentation about a topic from disciplinary research related to the theme of the course. Dr. Carlos explicitly did not intend to ask for any participation in research activities from the students other than sharing of ideas. Dr. Carlos’s account of the course mode can be characterised as research-led. The students scored moderately low on all scales. Remarkably, the scale ‘quality of the learning environment’ (C; 4.20) was scored high. Furthermore, the students scored moderately high on stimulation to develop their research disposition (B1; 3.19), and were strongly motivated to pursue research (B3; 3.67).

Dr. Eliot’s general intention for his course was to acquaint students with research through invited speakers who gave a lecture about recent research. Dr. Eliot perceived his role as that of ‘chairman’, who introduced the speakers and described the relations between the various topics. The most important goal for Dr. Eliot was to motivate students for disciplinary research by presenting own research conducted within the institute. The description Dr. Eliot gave of this course can be characterised as research-led teaching. The students perceived a strong motivation for research (B3; 4.00) during the course meetings, and scored moderately high on the scale ‘attention to research’ (A1; 3.20). Furthermore, participation in research was scored very low (A3; 1.52).

Dr. Tanya’s description of the mode for this course can be characterised as research-led. The students did not perceive themselves as participants in research (A3; 1.70) during the course meetings, and scored moderately high on the scale ‘attention to research’ (A1; 3.30). Furthermore, participation in research was scored very low (A3; 1.52).
this course, but were highly motivated to pursue research (B3; 4.50). Furthermore, the students perceived a strong stimulation to develop their research dispositions during this course (B1; 3.93).

Descriptions of teachers who taught courses with a research-tutored mode

In a course with a research-tutored mode of the nexus, the emphasis is put on research products, such as the understanding of theories or models. Students are ‘participants’ involved in research activities, such as in writing about theories and models, or by giving presentations about a topic of interest.

According to Dr. Simon, not much attention would be given to scientific research during his course. Dr. Simon explained that he always tries to integrate own research of the faculty/institute into his courses, and believes that this is not done enough. During this course, the students would participate in literature studies, and not in empirical or experimental studies. The students would present their findings to their peers in a conference format. Dr. Simon considered the study of the literature an essential part of scholarly activity. During his course, Dr. Simon planned to focus on argumentation skills and competencies. This description was in line with a research-tutored mode of the nexus. The students in this course scored high on the scales ‘motivation for research’ (B3; 4.00), ‘recent research’ (A2; 3.90), and ‘stimulation of research disposition’ (B1; 3.43). None of the scales were scored low compared to the other courses.

Descriptions of teachers who taught courses with a research-oriented mode

In a course with a research-oriented mode of the nexus, the emphasis is put on research processes, such as the gathering and analysis of data. Students are involved as ‘observers’ of the research activities, such as in repeating well-known experiments to develop certain research skills.

Dr. Charles explained that during his seminar, a combination of lecture and project, he planned to accustom students with and evaluate those elements of recent research which they would encounter during their professional careers. Dr. Charles explained that his own fundamental mathematically oriented research would not be appropriate to discuss during this practice-oriented course. Dr. Charles explained that his own fundamental mathematically oriented research would not be appropriate to discuss during this practice-oriented course. He explicitly looked for ways to motivate students for disciplinary research. Dr. Charles’ description of his course resembled the research-oriented teaching mode of the nexus. Students scored low on almost all scales, except for the scales ‘motivation for research’ (B3; 3.04) and ‘quality of teaching’ (C; 3.55). The scale ‘own research of teacher’ (A4; 1.53) was scored lowest of all scales and of all courses by the students.

Dr. Howard explained that his course would focus on the development of practical skills. According to Dr. Howard, scientific research will not be part of this course. Only on second thoughts did Dr. Howard explain that the assignments would, in fact, have various research contexts. However, he said that although the assignments would be contextualised, the problems would be more general disciplinary problems. And the problems were designed to allow students to develop their problem-solving skills. Some issues, which were still open questions in the field of disciplinary research, were presented to the students in an adapted form. This course had a research-oriented teaching mode of the nexus. The students in this course judged the intensiveness of research in education as low (A1; 1.95).

Dr. Nathan explained that his seminar was intended to integrate teaching of skills with lecture-type activities. According to Dr. Nathan, during each component of his course, the level of attention given to research will be high. He illustrated this with examples in which students were presented with assignments from the context of disciplinary research, for example, with research data from earlier research. Students were expected to use this existing data to train their analyzing skills. He stated explicitly that the focus would not be on recent research or the research of the teacher. An explicit learning goal in this course was to stimulate the development of a research disposition while working on the interpretation of data. The explanation Dr. Nathan gave about the mode of this course could be characterised as research-oriented. The student scores on the questionnaire showed that this course scored high on the scale ‘motivation for research’ (B3; 3.77). Furthermore, according to the students, the development of their research disposition was stimulated to a moderately high degree (B1; 3.17). Students scored low on the scale of ‘own research of the teacher’ (A4; 2.12).
In her practical course, Dr. Susan planned to pay explicit attention to bringing fun back into the practicals. She aimed to achieve this through contextualization of the assignments, demonstration of novel experiments using materials from the laboratory, and description of the links with her own research experiences. Dr. Susan paid much attention to explaining and showing how to do disciplinary research. Dr. Susan’s account of her course can be identified as research-oriented mode. All scores on the student questionnaire were moderately high, ranging from 3.82 (C) up to 2.52 (B2). Motivation for research scored moderately high (B3; 3.50), as did attention to research (A1; 3.55).

Table 3. Teachers’ intentions and students’ perceptions of the research intensiveness of the learning environment

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Mode of the nexus</th>
<th>Attentiveness to doing research (A1)</th>
<th>Acquainting with recent research (A2)</th>
<th>Participating in research (A3)</th>
<th>Using research of teacher (A4)</th>
<th>Stimulating scientific research disposition (B1)</th>
<th>Integration in a research community (B2)</th>
<th>Motivation for research activities (B3)</th>
<th>Quality of learning environment (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Carlos</td>
<td>Led</td>
<td>2.95 (1.32)</td>
<td>3.33 (1.27)</td>
<td>2.00 (0.87)‡ +</td>
<td>2.25 (0.50)</td>
<td>3.19 (.73)‡ -</td>
<td>2.67 (.01)</td>
<td>3.67 (.58)</td>
<td>4.20 (.35)</td>
</tr>
<tr>
<td>Dr. Eliot</td>
<td>Led</td>
<td>3.20 (0.70)‡ +</td>
<td>3.79 (.75)‡ +</td>
<td>1.52 (0.52)</td>
<td>2.94 (.96)‡ -</td>
<td>2.88 (.75)</td>
<td>3.00 (.90)</td>
<td>4.00 (.91)‡ +</td>
<td>3.56 (.81)</td>
</tr>
<tr>
<td>Dr. Tanya</td>
<td>Led</td>
<td>3.09 (.64)</td>
<td>3.60 (1.13)‡ +</td>
<td>1.70 (.71)‡ +</td>
<td>2.75 (1.41)</td>
<td>3.93 (3.0)‡ +</td>
<td>2.50 (1.18)</td>
<td>4.50 (.24)</td>
<td>4.60 (.57)</td>
</tr>
<tr>
<td>Dr. Simon</td>
<td>Tutored</td>
<td>3.77 (.84)‡ -</td>
<td>3.90 (1.00)</td>
<td>2.20 (1.13)</td>
<td>3.75 (1.06)‡ +</td>
<td>3.43 (1.01)</td>
<td>3.33 (1.94)</td>
<td>4.00 (1.94)</td>
<td>3.80 (.42)</td>
</tr>
<tr>
<td>Dr. Charles</td>
<td>Oriented</td>
<td>2.57 (.48)</td>
<td>2.10 (.94)‡ -</td>
<td>2.83 (.59)</td>
<td>1.53 (.82)‡ +</td>
<td>2.76 (.52)</td>
<td>2.33 (.71)</td>
<td>3.04 (.79)‡ -</td>
<td>3.55 (.50)</td>
</tr>
<tr>
<td>Dr. Howard</td>
<td>Oriented</td>
<td>1.95 (.75)‡ +</td>
<td>2.10 (.72)</td>
<td>1.43 (.55)</td>
<td>1.35 (.45)</td>
<td>2.02 (.74)</td>
<td>1.76 (.75)</td>
<td>2.32 (1.00)</td>
<td>3.75 (.84)</td>
</tr>
<tr>
<td>Dr. Nathan</td>
<td>Oriented</td>
<td>3.95 (4.7)‡ +</td>
<td>3.61 (.51)‡ -</td>
<td>2.31 (.92)</td>
<td>2.12 (.60)</td>
<td>3.17 (.67)‡ -</td>
<td>2.65 (1.97)</td>
<td>3.77 (.70)</td>
<td>3.77 (.71)</td>
</tr>
<tr>
<td>Dr. Susan</td>
<td>Oriented</td>
<td>3.55 (5.8)‡ +</td>
<td>3.20 (.73)</td>
<td>2.60 (1.01)</td>
<td>2.90 (.65)</td>
<td>2.87 (.57)</td>
<td>2.52 (1.02)</td>
<td>3.50 (.77)‡ +</td>
<td>3.82 (.45)</td>
</tr>
<tr>
<td>Dr. Adam</td>
<td>Based</td>
<td>3.62 (.70)</td>
<td>2.53 (.69)</td>
<td>2.20 (1.2)§ -</td>
<td>1.87 (.53)</td>
<td>2.70 (.53)‡ -</td>
<td>2.04 (1.74)</td>
<td>3.11 (.44)</td>
<td>3.83 (.34)</td>
</tr>
<tr>
<td>Dr. Edward</td>
<td>Based</td>
<td>3.82 (1.8)‡ +</td>
<td>3.87 (0.8)</td>
<td>3.67 (1.4)‡ +</td>
<td>3.83 (1.8)‡ +</td>
<td>3.19 (.59)</td>
<td>3.11 (.84)</td>
<td>3.56 (.58)</td>
<td>3.77 (.32)</td>
</tr>
<tr>
<td>Dr. Paul</td>
<td>Based</td>
<td>4.14 (1.9)‡ +</td>
<td>3.80 (1.2)</td>
<td>4.40 (0.7)‡ +</td>
<td>4.38 (.53)‡ +</td>
<td>3.93 (.30)</td>
<td>4.00 (1.47)</td>
<td>3.83 (1.24)‡ +</td>
<td>3.55 (.07)</td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td>2.92 (1.07)</td>
<td>2.82 (1.01)</td>
<td>2.04 (.96)</td>
<td>2.04 (.98)</td>
<td>2.65 (1.84)</td>
<td>2.30 (.94)</td>
<td>3.12 (1.05)</td>
<td>3.77 (.68)</td>
</tr>
<tr>
<td>Consistency Rate</td>
<td></td>
<td>5 out of 7</td>
<td>2 out of 4</td>
<td>4 out of 5</td>
<td>4 out of 5</td>
<td>1 out of 4 --</td>
<td>3 out of 4 --</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

# strongly part of intention of the teacher; ‡ not part of intention of the teacher
+ congruent; perceptions larger than 3.50 for intended elements and smaller than 2.50 for elements not part of the teachers’ intentions
- incongruent; perceptions smaller than 3.50 for intended elements and larger than 2.50 for elements not part of the teachers’ intentions

Descriptions of teachers who taught courses with a research-based mode

In a course with a research-based mode of the nexus, the emphasis is put on research processes, such as the gathering and analysis of data. Students are ‘participants’ in research activities, such as in research internships or open experiments during research practicals.

Dr. Adam explained that the focus of his course was to prepare and conduct scientific observations using methods commonly applied in the discipline. Student participation in research activities was central. Students made observations to solve a more or less open problem. An important teaching goal was that the development of students’ research disposition was provoked and stimulated. Dr. Adam explicitly explained his awareness that each student (and each scholar) needed to develop his/her own research disposition. Therefore, he perceived a need to differentiate between students in order to provide each student with the correct feedback during the course. A research-based mode characterised this course best. Students scored moderately high on the scale ‘attention to research’ (A1; 3.62), and very low on the scale of ‘own research of teacher’ (A4; 1.87). The students in this course scored relatively low on the scale ‘stimulating a research disposition’ (B1; 2.70). Students scored the quality of teaching in this course high (C; 3.83).
According to Dr. Edward, many research elements would be intertwined in this course. The students participated in parts of Dr. Edward’s own research activities. He aimed to give students the chance to practice with all kinds of experimental research practices in the discipline. His course resembled a research-based mode. The students (n=3) scored high on ‘recent research’ (A3; 3.80) and on ‘own research’ (A4; 3.83).

According to Dr. Paul, research was an essential part of this course. Students participated in the research of a PhD candidate studying under Dr. Paul, and thus were working on recent issues in the disciplinary research field. He emphasised the relevance of the experiments to the students, explicitly stating the goal to increase student motivation for research. This description of resembled the research-based mode of the nexus. The students (n=2) scored high on ‘recent research’ (A3; 4.40) and on ‘own research’ (A4; 4.38). The scale ‘quality of teaching’ (C; 3.55) scored lowest of all the scales of this courses; the rest of the scores were all above 3.80.

Congruence between teachers’ intentions and students’ perceptions

Table 3 depicts the average scores of the students’ perceptions per teacher and per scale. Those elements to which the participating teachers explicitly referred in their interviews as intentions for their courses and the elements which the teachers explicitly identified as not intended for the course are distinguished using separate symbols in Table 3. Congruent elements are marked with a plus sign, incongruent elements with a minus sign. Generally, the results presented in Table 3 reveal that 19 out of the 29 (66%) teachers’ intentions related to the research-teaching nexus which were explicitly mentioned were in line with students’ perceptions of the learning environment. Overall, based on the consistency rate presented in Table 3, consistency in teachers’ intentions and students’ perceptions can be discriminated. Three scales show consistency between teachers’ intentions and students’ perceptions, namely, ‘participating in research’ (A3; 4 out of 5), ‘using research of teacher’ (A4; 4 out of 5), and ‘motivation for research’ (B3; 3 out of 4). Two scales show low consistency, namely, ‘becoming acquainted with recent research’ (A2; 2 out of 4) and ‘stimulation of research dispositions’ (B1; 1 out of 4). The scale ‘attentiveness to doing research’ (A1; 5 out of 7) shows limited consistency. The scales which were, on average, rated highest by the students are ‘motivation for research activities’ (B3; 3.12) and ‘quality of the learning environment’ (C; 3.75). Notably, the two courses which scored highest on the scale ‘quality of the learning environment’ (C) are two research-led courses. Furthermore, the results on the scale ‘participating in research’ (A3) are notable, because all research-led courses show scores lower than average, while research-based courses show scores higher than average. This is in line with the ‘student participation’ versus ‘student observation’ dimension described by Healey (2005b), on which research-based education scores high on student participation in research activities, whereas research-led courses score high on student observation of research.

Conclusions and discussion

Congruence between teachers’ intentions and students’ perceptions

The central research aim was to establish associations between teachers’ intentions and students’ perceptions of the research intensiveness of university science courses. Generally, the results indicate that teachers’ intentions are moderately congruent (66%) with students’ perceptions of the research intensiveness of the learning environments. Teachers’ intentions regarding the participation of students in research activities (A3) and using own research during the course (A4) were most often coherent with students’ perceptions, while the stimulation of the development of research dispositions (B1) was least often coherent with students’ perceptions. Participation in research activities and using research of the teacher during a course can both be categorised as tangible elements of the research-teaching nexus; stimulation of the development of students’ research dispositions is an intangible element of the nexus. This result indicates that intentions about tangible elements are more coherent with students’ perceptions than intangible elements. This can be explained in at least two ways. First, intangible elements are more difficult for students to perceive than tangible elements. Second, intangible elements might be more difficult for teachers to emphasise. Therefore, teachers’ intentions such as the stimulation of the development of research
dispositions or the creation of an inquisitive atmosphere are more likely to be incongruent with students’ perceptions than are teachers’ intentions such as participation in research or using own research. This suggests that misunderstandings about intangible elements of the research-teaching nexus are more likely to occur than misunderstandings about tangible elements of the nexus. It is advisable for teachers to keep in mind that such misunderstanding about the intangible elements might lead to unexpected and diffuse notions of the nature of scientific inquiry.

These results also suggest that students perceive the development of their research dispositions less clearly during courses with a research-oriented mode than in courses with other modes of the nexus. A possible explanation is that when a student is following a course aimed at improving skills, it is more difficult for him or her to reflect on research processes or on research dispositions. Reflection on research processes and dispositions might be stimulated best through observation of others, such as peers and experts, or through conducting authentic research in which the focus lies on the development of new knowledge, such as in courses with a research-based mode. In research-oriented courses the development of students’ research dispositions might be stimulated through the creation of a critical and innovative atmosphere. Attention should be paid to the fact that when students are actively involved in the training of research skills the stimulation of the development of their research dispositions might not be perceived by them, although the teacher works on it constantly. Here, we assumed that both explicit attention of the teacher and awareness of the students are necessary for the development of appropriate research dispositions. Students’ reflection on aspects of their own research dispositions can help them to focus on tacit elements of research, and can probably best be done before or after the assignments.

Some teacher intentions which were perceived clearly by the students were not mentioned by the teachers during the interviews as explicit intentions for the course. Dr. Simon, for example, did not explicitly intend to acquaint students with recent research (A2), nor did he explicitly intend to motivate students to pursue research (B3), but his students perceived both elements clearly in the course (A2, 3.90; B3, 4.00). Some teachers possibly did not consider it worthwhile to mention that specific intention during the interviews because they may have perceived it as obvious to have that intention, or that particular intention was not explicitly a learning goal or teaching goal for the teacher, but a thing he/she did implicitly pay attention to.

Limitations and suggestions for further research

Student scores on the questionnaire depend not only on students’ perceptions, but also on their expectations. This might give an explanation of the result that students in a research-led course perceived the quality of the course and their motivation for research very clearly, while we expect that a course in which the teacher transmits knowledge by direct instruction would not always stimulate motivation for research, nor be considered a high-quality learning environment. Thus, the results of this study can not be used to compare between cases, but they may provide information about associations within cases. Furthermore, it might be interesting, in future research, to relate teachers’ intentions to a combined measurement of students’ perceptions and expectations, in order to gain a greater understanding of possible associations between teachers’ intentions and overall student experiences.

Students’ perceptions of different kinds of learning environments were investigated in this study. The results suggest that there are differences and similarities in students’ perceptions of learning environments. The evaluation of students’ perceptions of the constructed learning environments can be an effective tool to stimulate teachers to reflect on their own teaching practices. The questionnaire used in this study might be used as an evaluation tool for teachers to become aware of students’ perceptions of the constructed learning environment, and specifically to become aware of students’ perception of research activities in their courses.

The results of this study show that teachers’ intentions related to tangible elements of the nexus are relatively more coherent with students’ perceptions than teachers’ intentions regarding intangible elements of the nexus. This invites us to develop awareness among academics that the development of students’ research dispositions, as an
intangible element of the research-teaching nexus, needs explicit attention if we want students to perceive and appreciate research dispositions in their studies and later in their careers.

References


TOWARD INTEGRATED ICT CLASSROOM FOR EFFECTIVES TEACHING AND LEARNING SCIENCE: ISSUES AND CONSTRAINTS FROM MALAYSIAN SCHOOLS CONTEXT

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Universiti Kebangsaan Malaysia

Abstracts

Malaysian has intention to move forward to achieve a develop country status by Year 2020, the government is taking several initiatives to increase the role of science and technology education. Malaysian school science education curriculum has periodically undergone reviews which aim at continuously improving science teaching and learning. Innovative teaching and learning strategies espoused in each review are being disseminated to the teachers. Support in terms of teaching and learning materials and educational technologies in line with the innovative teaching and learning strategies are also provided by the Ministry. However the effects of curriculum changes such as the effect of a new teaching method on the classroom’s environment or whether existing classrooms environment supports the innovative teaching strategies are often neglected (Fraser 1994 and Emmer et al 2003). For example, prevailing pedagogies based on theory of situated learning (Brown et al. 1989) and social constructivism theory (Berk & Winsler 1995; Hassard 2006) emphasized on active as well as collaborative and technological related skills, which are increasing central to learning in age when human lives are immersed in electronic technologies; however the current science classroom design and environment do not reflect this especially in the Malaysian context. In order to promote scientific and technological literate, Malaysia need science and mathematics educators who are skilled and knowledgeable to educate pupils. Therefore classroom learning environment should be design to suit the needs. This paper will present the current situation of the integrated ICT classroom, issues, constrains and how its suitability for effective science teaching and learning.

Introduction

In recent year, many educational reforms are occurring all over the world, especially when new innovations and ideas about teaching and learning are to be experimented with and implemented. Improving and raising the quality and effectiveness of the teaching and learning process has been identified as underpinning these reforms (McLaughlin, 1997). By having said that, so many factors contributed to achieved educational goals. To date, the implementation of new information and communications technologies (ICTs) in classroom occurring all over the world. Educators and administrators must provide a new approach of teaching and learning. Internet is viewed by many educators as a new and potentially powerful teaching medium, but the effectiveness of its use in classroom depends on the quality of the teaching not the technology (Adams, Carlson & Hamm, 1990; Jonasson 1994). In this way, the internet can be viewed as a tool for realizing many educational reforms. Further, the use of computer networks has the potential to transform physical and psychosocial classroom environments in either negative or positive ways. Huge amount of money currently being spent for the implementations of ICT, so educators and bureaucrats are also expecting return in the form of greater educational productivity from students (Zandvliet & Straker, 2001).

A growing amount of interest within the field of educational research has been focused on what is described as the classroom learning environment (Fraser, 1991, 1998, Fraser & Walberg, 1981, Moss 1973). This interest is also share to some extent by other researchers in other fields such as sociology, psychology and so on. The interdisciplinary nature of such research points in part to the bewildering number of factors which ultimately may
influence learning. A previously noted, the remaining factors which can influence learning can be grouped roughly into the categories corresponding to the physical and the psychosocial spheres in Gardiners’ Model (1989). The Gardiners’ Model has been further adapted by this researcher to provide the theoretical framework. In an educational setting, Gardiners’ model can be adapted, so that the physical classroom environment represents the ecosphere, the psychosocial classroom environment represents the sociosphere, and finally the implementation of new educational technologies represents the technosphere component of the model. All these are considered as they are associated with student satisfaction. This model is presented as Figure 1 below:

![Figure 1: A Conceptual model for studying educational change (adapted from Gardiner 1989)](image)

This study, tried to identify the existing physical features of classroom issues and constrains and to propose integrated classroom to cater need for the various kinds of pedagogies in teaching and learning.

**Rational**

Current trend and future direction in science education in Malaysia undergone reviews which aim to improving science teaching and learning (CDC 2001). Our Ministry has done a lot of programs to upgrade quality in teaching and learning science such as: a) implementation, ETeMS (English for Teaching Mathematics and Science), b) Integration of ICT in teaching and learning: Every classroom fix with one LCD, OHP and screen, and a courseware for science subject and c) revised curriculum. This types of classroom identified for the purpose of this study could be described as “technologically-rich” classroom (those having a set of desktop computer, internet access, LCD and screen). But how far the initiatives propose by the government suits the existing physical features of the classrooms. So a lot of issues and constrains to be explore. Adam (1991) stated that the successful use of computer means involved students and educators in the learning process in a new way. As with any medium, the vitality of computer use in schools depend on good teaching. Profesional knowledge about student learning, curricula, and classroom organization should complement other important information on effectives, productive and safe computer use by students. The current learning environment (physical and non-physical factors) does not provide opportunities among others; areas that support science learning also areas that are easily and quickly changed moment to moment (Wolff, 2002). Ofsted (2004) report about the integration of ICT in school. The impact of government initiatives shown the main finding of the applications of ICT in science lessons is generally making a good contribution to pupils’ achievement.
Methods

This study used a qualitative method. Data were collected using interviews and discussion with teachers experience teacher (more than 10 years teaches science) and students. Face to face interview have been done with teachers in order to get more information about the constraint that they faced while teaching science especially related with their classroom learning environment. This study aims to develop the concept and design of the identified integrated classroom for teaching and learning. This early stages phase of this study is:

• To identify the existing features of the physical classroom arrangement for teaching and learning science and how they utilised.
• To identified and list down issues and constrains of their classroom learning environment from the teachers and students perspectives
• To suggest the integrated classroom based on teachers, student’s perspective and literature reviews.

Results

A major issues and constrains was highlighted by the students and teacher are:

i. Our schools’ model, which comprises of the teaching spaces (classrooms, laboratories, and libraries), administrative areas and social and leisure environments, remained largely unchanged throughout the twentieth century. Most of the existing features of the physical arrangement of the classroom still based on pre independence design. Architects are not deeply familiar with science teaching and learning in school contexts, recent science curriculum changes, or the differences between science teaching facilities and other teaching spaces lack of arrangement and space for some activity. The number of the students for each class around 35 - 40 students.

ii. Science teaching spaces are often undersized, creating safety issues and limiting the teacher's ability to effectively carry out a program of hands-on, inquiry-based instruction and so on.

iii. Budgets for new construction and/or renovation are often set with little or no input from science educators and thus provide too little funding to complete a successful science facility.

iv. This arrangement typifies an authority structure and power relation that undermines the creation of the more collaborative learning communities.

v. Lack of space for some material and references.

vi. Shortages of computer and internet line. Computer provided only for ETEMS teacher, there is no computer for student and no internet access in some of the classroom. Students’ complaint that the white screen blocked the blackboard and should appropriate in size so that the entire student can see the presentation clearly. Several factors have been identified in studies related to computer-based technologies and science teaching (Tebbutt, 2000; Ng & Gunstone, 2003).

vii. Take time to set-up LCD and computer (too many wire, plug and extension to plug-in) insufficient time to conduct a multimedia presentation.

viii. Ventilation issues, classroom become too hot during afternoon class and the student cannot concentrate to their learning.

ix. Lack of maintenance for some technology apparatus and

x. Quite noisy especially classroom near the road or cafeteria

Besides that, Rohaida Mohd. Saat and Kamariah Abu Bakar (2005) stated among the factors that influence the use of technology in science teaching are: (a) the difficulty in getting access to computers, (b) associated equipment or hardware, (c) time, (d) teachers' lack of skills and knowledge in information technology and communication (ICT), and (e) lack of financial support. All these factors were found to have hindered teachers from teaching using computer-based technologies. From the students’ and teachers’ interview, all agreed that it was beneficial to bring more computers (ICT) into the classroom. They all agreed that ICT has many advantages to students’ learning. The students’ attracted to ICT features that could not be found in other media.
Conclusion and Implication

To cater for the need of the next generation, the government should move to design an integrated ICT classroom for the adaptability and flexibility multiple of pedagogies. According to Schofield (1995) ICT lead to promoting motivation as well as catering for their learning need. Students’ motivation can also be seen through the classroom dynamic, including interaction among students, teachers and technology. The physical arrangement of the classroom can serve as a powerful setting event for providing students effective instruction and facilitate positive teaching/learning interaction. Thus, the school/classroom planners must cooperate closely with educators to design integrated ICT classroom to fulfill needs for effective teaching and learning science. The data shown that, classroom should be organized to accommodated a variety of activity throughout the day to meet teachers instructional goals. Among that are:

d. Incorporate flexibility in physical setting of classroom

The physical setting or environment also played an important role in the present learning environment. Johnson (1997) regarded an ideal environment as a significant factor in promoting learning. This environment includes the physical setting of the classroom. Based on observations, the physical setting of this study could have hindered direct interaction between students and teacher, especially during the latter’s explanations on various concepts or issues. According to Strange and Banning (2001), classroom design for example, should be design to stimulate the senses of the users. The built learning environment should provide a sense of one’s own space, connection with others, meaningfulness and relevancy to the world. The key features of space designed for active learning, specifically for collaborative has been identified as providing a sense of belonging, the need for flexible and multi-use spaces, and recognizing the use of non-classroom spaces for learning.

The situation could probably be improved with the rearrangement of the physical setting. For instance of the computer laboratory, computer stations could be arranged facing the wall, leaving empty spaces in the middle. Chairs could be brought to the middle and students could sit in this empty space while listening to the teacher. The students could only go back to the computer station once they were ready to work with the computer (Rohaidah Mohd. Saat and Kamariah Abu Bakar, 2005)

e. Integration ICT in classroom

Various survey suggest that access to ICT by teachers and learners is increasing dramatically and that the quality of this provision is also improving (Ofsted 2002). The role of ICT (Information Communication Technology) in science education has been widely justified. From their literature review Osborne and Hennessy (2003) discuss a number of reasons for using technology in science teaching and learning including; expediting and enhancing work production; increasing the currency and scope of reference and experience; supporting exploration and experimentation; fostering self-regulation and collaborative learning and finally, improved motivation and engagement. Teachers’ thought that technology proved particularly powerful when exploiting interactivity and dynamic visualization making scientific concepts and processes clearer (Ruthven et al., 2004). In some cases multimedia simulation was integrated and sequenced with complementary work (practical, exposition, plenary discussion) using projected simulation to provide visual stimulus for questioning and reasoning, and for knowledge-building.

References


SOCIO-SCIENTIFIC COLLABORATIVE INQUIRY IN ASTROBIOLOGY
– THE DESIGN AND IMPLEMENTATION OF A DIGITAL LEARNING ENVIRONMENT
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Abstract
In a European project – CoReflect – researchers in seven countries are developing, implementing and evaluating teaching sequences using a web-based platform (STOCHASMOS). The interactive web-based inquiry materials support collaborative and reflective work. The project methodology is based on the idea of design-based research, which seeks to bridge the often disconnected worlds of academia and educational practices. Hence, the teachers are engaged throughout the project. The learning environments will be iteratively tested and refined, first as pilot projects, then during local implementations, and finally during implementations and synthesis work at the European level. All learning environments are focusing “socio-scientific” issues. In this article we report from the pilot of the Swedish learning environment with an Astrobiology context. The socio-scientific driving questions were “Should we look for, and try to contact, extraterrestrial life?”, and “Should we transform Mars into a planet where humans can live in the future?” The students are in their last year of compulsory school (16 years old), and worked together in triads. We report from the groups’ decisions and arguments used. A majority of the groups express reluctance towards both the search of extraterrestrial life and the terraforming of Mars.

Introduction
Young peoples’ lack of interest in science and science intense educations and occupations are a big concern for many stakeholders in western societies (e.g. 2005; Sjøberg & Schreiner, 2005; Tytler, 2007). This has led to a call for a renewal of science education, so that more students feel that science is of relevance and importance for themselves, and for the society as a whole. There has also been an increasing acknowledgement of the importance of scientific knowledge among people, to make an active and informed citizenship possible. Hence many science education researchers suggest that work with “socio-scientific issues” should become part of science teaching (Sadler, 2004).

“Socio-scientific issues” can be defined in different ways. They include a scientific dimension, but also other dimensions like economical, aesthetic, ethical and social aspects. We agree with Zeidler et al. (2002) that the term socio-scientific issues take a broader perspective than Science Technology and Society (STS). They state

“STS education, while typically stressing the impact of decisions in science and technology on society, does not mandate explicit attention to the ethical issues contained within choices about means and ends, nor does it consider the moral development of the students” (Zeidler et al. 2002, p. 344).

There is often disagreement within the scientific community concerning scientific questions of relevance for a socio-scientific issue. There is a difference between “socio-scientific issues” where the science community agrees about the scientific dimension compared to those where there are disagreement. The latter are more complex, and Kolsto (2006) states that persons involved (decision-makers) have two main questions to consider.
“First, there is the ethical, personal, or social question related to what scenario to prefer or what actions to take. Second, the decision-maker might need to make a decision on the scientific question involved” (p. 1690).

Research shows that students and people in general (e.g. Ryder, 2002) often do not give high priority to science knowledge when making decisions. One explanation for this is that socio-scientific issues discussed often do not concern “core science”, but “frontier science” on which there is much uncertainty, and no consensus view within the science community (Aikenhead, 2006, p. 101-102).

An individual’s decisions on “socio-scientific” issues depend of her/his values and worldviews. What the right decision is depends on how one thinks about the world we live in, and how one values the costs and benefits. Worldview can be defined in different ways, but here we follow Kearney (1984). His model was adapted to a science education context by Cobern (1991, 1996). An individual’s worldview constitutes a basis for how he or she thinks about and understands specific phenomena, for example phenomena relevant for making a decision on a “socio-scientific issue”. Worldview also lies behind an individual’s judgement on what kind of knowledge that is important:

“Worldview provides a nonrational foundation for thought, emotion, and behaviour. Worldview provides a person with presuppositions about what the world is really like and what constitutes valid and important knowledge about the world” (Cobern, 1996, p. 584)

Examples of such presuppositions are that nothing more than the material world exists, that everything has a meaning, that there are patterns in nature that are possible for humans to understand, that nature is superior humans, and that a god can exist and interfere in the world.

Not only every individual but also all knowledge systems, for example science, are built upon presuppositions that are not possible to prove within the system itself (Cobern, 1991; Cobern, 1996; Trusted, 1991). There are partly different views within the science community concerning which presuppositions that science builds upon. But even though different scientists have slightly different views on this there is also what Cobern (1991) calls a “lived worldview”. This lived worldview consists of presuppositions that are taken for granted by most scientists in their daily work. Poole (1998) states that presuppositions shared by most scientists are

- “human reason is generally reliable,
- there is regularity and order in the universe,
- humans can discover and understand something of that order,
- there is a basic uniformity in the behaviour of the natural order, in space and time” (Poole, 1998, p. 186)

In a similar way Cobern & Loving (2000c) describe a “metaphysical minimum for science” and state that science take a starting point in that “the possibility of knowledge about nature”, “that there is order in nature” and “causation in nature”. However, these presuppositions are not always shared by the students and the students do not always or easily see that these presuppositions are associated with science (Hansson & Redfors, 2007). This is a possible problem for students about to learn science. For example if you do not know that science takes as a point of departure that there are order in nature, and that the theoretical models we construct are valid over time and space, it is difficult to in a meaningful way understand scientific models of how the Universe develops over time, or how stars are “born” and “die” (Hansson & Redfors, 2007).

How can this be handled in the science classroom? In the teaching of science the focus is often on different phenomena and models linked to these. According to a worldview perspective (Cobern, 1991, 1996) one also has to work with a more profound level of the students’ thinking – that is the presuppositions that the students have about the world. These have to be related to the presuppositions that underpin science:

“the strategy and tactics of science education need to be formulated as an analog to the macrolevels (worldview or level of fundamental presuppositions) and microlevels (conceptual level) of a everyday thinking” (Cobern, 1996, p. 591).
In this way more students can get knowledge about the presuppositions underpinning science, which makes it possible for them to understand also the specific models taught in the science classroom.

To include “socio-scientific issues” in the teaching of science prepares youths to deal with questions that they will meet as citizens in a democratic society. It is also a way to make science relevant for greater numbers of students. Yet another strategy to make science more appealing, and promising for meaningful learning, is to integrate new technologies (ICT) in the teaching. This article is a report from a pilot study within the European project, CoReflect (www.coreflect.org). Within this design-based project (Barab & Squire, 2004) the researchers together with teachers design digital learning environments about different socio-scientific issues. The web-based learning environments in this project are used to scaffold collaborative settings. The researcher-teacher groups in the different countries design one learning environment each, on different socio-scientific issues. In the first phase of the project we are piloting the learning environments in our own countries. In this article we report from this piloting phase in Sweden. In a later phase of the project we will implement the learning environments in other countries and study this implementation phase too learn about what changes that have to be done to accommodate different school systems, cultures and traditions.

The Swedish group has chosen to design a learning environment dealing with the scientific content area of Astrobiology. Astrobiology is a relatively new area of research that deals with questions related both to biology, astronomy/cosmology/physics, and chemistry. At the most profound level Astrobiology questions are questions like “Does life exist outside Earth?”, but to come closer to an answer to that question one tries to answer questions about the physical and chemical conditions for life, and how to establish whether or not a distant planet harbour life. Astrobiology researchers therefore try to detect planets that could be similar to the Earth, and try to understand more about the conditions for and origin of life on Earth. The possibility to detect planets orbiting other stars is a rather new one, and has made the research area of Astrobiology expand. These results have also reached the broad public, since they have been reported in daily newspapers. Astrobiology questions are of existential value for many people, and Astrobiology is also an area that we believe fulfils many of the things that young people today are interested in: much of it is unknown, it raises philosophical questions, which has been shown by ROSE (Sjøberg & Schreiner, 2006) to be of interest to many youths.

Rationale

The first aim of this article is to describe the learning environment and the thoughts behind. The second aim is to describe the results of the students’ decisions concerning the socio-scientific driving-questions, together with what kind of arguments the students use and value as important.

Methods

The data that this article builds upon comes from the implementation of a pilot version of a digital learning environment focusing socio-scientific issues in the context of astrobiology, designed within the European project CoReflect. We will first briefly describe the digital learning environment, the implementation, and after that the kind of data collected and analysis performed.

The learning environment

The web platform used to set up the learning environments within the CoReflect project is STOCHASMOS (Kyza & Constantinou, 2007). This platform is made up by two environments. The teacher authoring environment supports teachers in building or customizing and managing multi-modal, web-based inquiry environments and enables them to get asynchronous access to their students work. The learning environment allows students to collect and value information and arguments, explain their thinking, construct, and finally communicate their argumentation concerning a socio-scientific issue.
The teacher’s asynchronous access to their students’ work means that a teacher can review a group’s work and add comments to their workspace pages, thus providing feedback the students can view and use at the beginning of their next lesson. Furthermore, the history log of the tool can give teachers information on which inquiry environment pages the students have visited and the time between accessing each of the web-pages stored in the STOCHASMOS system.

Learning environments of STOCHASMOS consist of different parts – “the inquiry environment” and the “work space”. In the inquiry environment the missions are presented, and the students can also find information that they could use developing their arguments. In the workspace students are asked to work with different activities, and also to gather information and arguments relevant for the missions. There is also a Chat, a Notebook and a Forum; these tools are accessible from both workspace and inquiry environment. Through the chat it is possible to communicate with one peer-group. It is also possible for the students to share pages in the workspace with this peer-group. The students were introduced to STOCHASMOS by working with a detective story – as detectives, solving a theft of computers in a school. The detective story introduces them to the uses of the STOCHASMOS features. It also helps to focus on the role of evidence in argumentation.

The missions

In the inquiry environment two missions were given to the students. The second mission was not shown to the students from the beginning. Both missions have socio-scientific driving questions, which include a scientific, but also economical, social and ethical issues are relevant.

- Should we look for, and try to contact, extraterrestrial life?
  - **Scientific aspect:** e.g. Probability to find life/intelligent life? What are the requirements for life? Where should we be looking?
  - **Social aspect:** e.g. Safety if we establish contact – for us, for them?
  - **Economical aspect:** e.g. How shall economical resources be spent?
  - **Ethical aspect:** e.g. How should we be looking for life? From Earth or through sending things out in space? Should we be leaving footprints? Interfere in the natural order?

- Should we try to transform Mars into a planet where humans can live in the future?
  - **Scientific aspect:** e.g. Probability to accomplish the project? What kinds of changes of Mars are necessary? How can it be done?
  - **Social aspects:** e.g. If it was possible to transform Mars, and humans could not survive on Earth – who will be allowed to go – who will decide?
  - **Economical aspect:** e.g. On what should economical resources be spent?
  - **Ethical aspect:** e.g. What kind of interventions should we do in our Solar System? Interference in the natural order?

In the first case the mission begin with a youth expressing concerns about possible life on other planets. The text is adapted from an actual blog in Swedish. The trigger for her/his thoughts is the publication of the first optical picture ever of an exoplanet, a planet outside our own solar system, see figure 1.
The second mission starts up with an interview with the first Swedish astronaut Christer Fuglesang where he describes his thoughts about space travels and the possibility that humans can live on Mars in the future.

**Framework and scaffolding**

The STOCHASMOS inquiry environment consists of ten tabs besides the two mission-tabs. There the students find information about the origin and development of the universe, the solar system, exoplanets, life and conditions for life, how to get information about the universe (pictures, spectra, space travels), terraforming, security issues, economy and ethical issues. The last tab is about lab work and describes the lab work the students are asked to do. There are two sessions in the laboratory. The first is connected to distances in the Universe and the student practice the direct method of triangulation. The second is connected to the analysis of element abundances in stars and galaxies. The students get to observe spectra – continuous spectra as well as absorption and emission spectra.

There is also one tab “On Science” which contains a text on the Nature of Science (NOS). The focus is on presuppositions, theories and models. Including this is a consequence of the worldview theory. Cobern states that

“the strategy and tactics of science education need to be formulated as an analog to the macrolevels (worldview or level of fundamental presuppositions) and microlevels (conceptual level) of a everyday thinking” (Cobern, 1996, p. 591).

With the text on presuppositions together with an activity we want to focus the students’ attention to the presuppositions of science. In teaching about the Universe and extra-terrestrial life you often encounter question from the students on the relationship between Science and Religion. Therefore, a text on Science and Religion is included and the students get to discuss this relationship. This is also linked to the presuppositions that are associated with science.

Scaffolding is important to make it possible for more students to engage in reasoning on an appropriate level. The student work in the workspace is of course scaffolded by the teacher in the classroom, meeting the students face to face. The student work is however also scaffolded directly by the design of the learning environment. For example, to scaffold the students learning in the inquiry environment, the texts includes questions for the student groups to discuss. An example of how questions are included is shown in figure 2, showing the main text under the tab “On Science”.

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**Figure 1. The first tab of the STOCHASMOS Inquiry Environment**

The second mission starts up with an interview with the first Swedish astronaut Christer Fuglesang where he describes his thoughts about space travels and the possibility that humans can live on Mars in the future.
Another way to scaffold the students’ work is through designed activities. There are activities on the presuppositions associated with science, Drake’s equation¹, and habitual zones². In addition to this the workspace of STOCHASMOS includes templates to help students structure their work and focus on relevant questions. In the workspace the students do all their work, but the reading part – they gather arguments and write conclusions. The students can create new pages using a predefined list of templates. There are templates to help students:

- keep track of their chosen path through the materials (All the tabs)
- make notes on their discussion (Group discussions)
- work with the activities and the labs (e.g. Drake’s equation)
- gather and fine tune their arguments (Concluding arguments)
- formulate their final standpoint (Final standpoint).

In the work space the students can access images of data, texts and figures taken earlier with the camera tool, and they can insert a number of things in their pages, e.g. textboxes, “stickies”, arrows, images and links to pages that have created earlier in the workspace. They are also asked to share their pages with a pair-group. There is a “History” feature which allows the students to view old versions of their pages.

The students are first introduced to the All the tabs template where they keep record of their progress through the learning environment. The template Concluding arguments is of special importance, see figure 3.

It helps the students to consider all four aspects of the socio-scientific driving questions. It also helps the students to recognise arguments in both directions concerning each aspect. It has been shown that evaluating different positions is central for effective decision makers (Lee, 2007). By continuously working with this template the students are given the possibility to enhance the basis for their final arguments, reported in the template Final standpoint no matter what path they have chosen to take through the learning environment.

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¹ Drake’s equation is used to estimate the number of current civilisations in the Milky Way.

² Habitual zones are spherical zones around a star where conditions for life, as we know it, are met.
The implementation

The learning environment was implemented in a student group that attend the last year of compulsory school (the year most of the students turn 16). Swedish students study science (including physics, chemistry, and biology), and the schools (and teachers) can choose whether the science subjects are integrated, or studied separately. The student group that worked with the pilot version of the learning environment studies the science subjects integrated. They were also used to non-teacher centred work – in groups and individually. There were 30 students in the group. The number of lessons was 13 including three lessons with the detective story. The students were working together in triads (groups with three students) in front of a computer.

Data collection and analysis

All computer activities were logged by STOCHASMOS. The arguments and decisions that the students have written in the templates of STOCHASMOS are therefore available for all student groups. Written pre- and post-instruments tested for students’ knowledge and inquiry-skills, worldviews, and motivation. In addition to this data was collected through audio-recording 6 of the 10 student groups throughout the teaching sequence. Follow-up interviews of single individuals were performed by the researchers.

During the implementation there were 1-2 researchers present in the classroom, managing video/audio recording and taking field notes. The researchers were trying not to take part in the teaching, even though some “teacher-like” answers to questions were given.

The analysis that this article builds upon is focusing students’ decisions and argumentation in their final statements of the groups. We are interested in what kind of arguments that the students tend to value as important.
Results

We will begin by describing the decisions and arguments of all ten student groups, and after that focus on the description of the work, argumentation, and decisions of one of the groups.

The decisions and arguments of the groups

During the work in the learning environment with the two driving questions the students collected arguments concerning scientific, social, economical and ethical aspects of the issues with the help of a template. With the starting point in those collected arguments the students were supposed to decide upon their views concerning the driving questions and formulate this view in a final statement for each of them. Looking at those decisions of the ten student groups concerning the two socio-scientific driving questions we can see that the most common answer is that we should not search for extra-terrestrial life, and we should not try terraforming Mars, see table 1.

Table 1. The groups’ decisions concerning the driving questions

<table>
<thead>
<tr>
<th>DRIVING QUESTION</th>
<th>YES (# of groups)</th>
<th>NO (# of groups)</th>
<th>NO STATEMENT (# of groups)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Should we look for, and try to contact, extraterrestrial life?</td>
<td>2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Should we try to transform Mars into a planet where humans can live in the future?</td>
<td>1 (not possible)</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

In the final statement the students were also asked to describe their arguments. There are differences as well as similarities in the arguments put forward by the groups in the statements. The arguments included in each one of the final statements were analysed, and the arguments were categorised based upon their content. The categories that were emerging from the analysis are presented in table 2.

As we can see from table 2 there are arguments concerning risks, possible achievements, costs & resource prioritizing, chance of succeeding and practical issues, environmental issues, and curiosity. Not all kinds of arguments were present in all student groups. For example, while most groups include economical arguments and arguments about risks, only one of the groups put forward arguments about curiosity. Possible development is not mentioned frequently either. Ethical arguments are seldom mentioned explicitly in the groups’ final statements. One group states that it is not right of us to try to form a life that is more convenient for us if it has negative consequences, and one group mentioned that we should not destroy more places than we already has.
<table>
<thead>
<tr>
<th>Table 2. Categories of student arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Searching for life</strong></td>
</tr>
<tr>
<td><strong>RISKS</strong></td>
</tr>
<tr>
<td>- safety during space travels</td>
</tr>
<tr>
<td>- conflict between humans and the other</td>
</tr>
<tr>
<td>intelligent species that we find</td>
</tr>
<tr>
<td>- we can bring back bacteria that could</td>
</tr>
<tr>
<td>cause diseases</td>
</tr>
<tr>
<td><strong>COSTS, RESOURCES, PRIORITISING</strong></td>
</tr>
<tr>
<td>- we should spend the money on other</td>
</tr>
<tr>
<td>things (e.g. the environment on the</td>
</tr>
<tr>
<td>Earth, people in developing countries,</td>
</tr>
<tr>
<td>medical research)</td>
</tr>
<tr>
<td>- maybe the money will be spent in vain</td>
</tr>
<tr>
<td><strong>CHANCE OF SUCCESS, PRACTICAL PROBLEMS</strong></td>
</tr>
<tr>
<td>- believe/do not believe that life exists</td>
</tr>
<tr>
<td>elsewhere</td>
</tr>
<tr>
<td>- believe life exists somewhere because</td>
</tr>
<tr>
<td>the universe is large</td>
</tr>
<tr>
<td>- low chance of finding life (planets are</td>
</tr>
<tr>
<td>far away, takes a long time to go</td>
</tr>
<tr>
<td>there, the universe is large we can’t</td>
</tr>
<tr>
<td>look everywhere...)</td>
</tr>
<tr>
<td>- Have only found planets where life</td>
</tr>
<tr>
<td>cannot exist</td>
</tr>
<tr>
<td><strong>CURIOSITY</strong></td>
</tr>
<tr>
<td>- we are curious</td>
</tr>
<tr>
<td><strong>ENVIRONMENTAL ASPECTS</strong></td>
</tr>
<tr>
<td>- CO₂ pollution by space travel</td>
</tr>
<tr>
<td>- important not to litter other planets</td>
</tr>
<tr>
<td><strong>TECHNOLOGICAL, DEVELOPMENTAL ASPECTS</strong></td>
</tr>
<tr>
<td>- could lead to higher intelligence and</td>
</tr>
<tr>
<td>improved technology</td>
</tr>
<tr>
<td>- natural resources, new fuel, help us</td>
</tr>
<tr>
<td>learn how to live in space</td>
</tr>
<tr>
<td>- not right for us to create better</td>
</tr>
<tr>
<td>living conditions if the Universe</td>
</tr>
<tr>
<td>must suffer</td>
</tr>
</tbody>
</table>

**Conclusions and Implications**

Most student groups decided that we should not look for extraterrestrial life, and neither should we try terraforming Mars. We have seen that the students in their statements put forward arguments of different kinds. Many of the students’ arguments are related to science, for example risks, chances of success and practical problems related to the missions. Economical arguments seem to be central and present in many of the groups. The same is valid for social aspects. Mostly this concerns arguments relating to different kinds of risks, but also arguments about the possibility that establishing contact with other life forms could lead to different kinds of development here on Earth. On the other hand ethical aspects are rarer. Aikenhead (2006) states that research shows that students are not
able to thoughtfully make decisions on controversial issues before the age of 15 or 16 years old (p. 104). The investigated students are in that age where they could begin to handle controversial issues. This means that there probably are many students in the group that have difficulties with this. Economical aspects are more familiar and easier for the students to handle, compared to ethical aspects. Economy and resource prioritising are often more explicitly discussed in the society than ethical issues are. In a study by Hansson & Lindahl (2007) where older students (18-19 years old) were interviewed about whether we should try to transform Mars into a planet where humans could live in the future, it was rather common that the students mentioned ethical issues, associated to their worldviews. There are students in that study that find it problematic to interfere in another planet which could then be spoiled. They claimed that humans should not/are not allowed to interfere in nature in that way, maybe because they are older and more familiar with ethical considerations. In that study the students also only stated their individual views, they were not asked to agree with others. Ethical arguments is harder to agree upon in a group because of their heavily dependence on worldview.

That the students seems to prefer or choose to use arguments concerning science, risks, chance of success, and economical arguments rather than ethical ones could also be strengthened by the context. The Astrobiology context is an area that many students are curious and interested in (Sjoberg & Schreiner, 2005). However, it is also a research area that is not highly prioritised by Swedish adults (Public & Science, 2009). Hence the area seems to be considered interesting, but not very important. This is a possible reason for the influence of economical arguments.

Concerning the science aspect of the issues most student groups include arguments in their final statements concerning that. Analysing the arguments that are included we have seen that many of them are related to science. Obviously there are arguments about the probability of success – Does extraterrestrial life exist? Could we go there? But science also constitute a background for arguments about what kind of risks we are prepared to take – for humans and for possible extraterrestrial life. Science therefore constitutes a background also for ethical and social aspects of the issues. Much of earlier research on students' reasoning on socio-scientific issues has shown that the students mainly focus on other aspects than science in their decision making (e.g. Ryder, 2002). This is not obvious from our analysis.

We will continue to analyse the students discussions during the teaching sequence to see how much science reasoning that really are present, and to find out how important science aspects are for their understanding and decision making on the issues. So far we can only conclude that they to a rather high extent include science related arguments in their final statements. Continuing the work we will analyse how the students’ worldviews can be related to their argumentation during the teaching sequence. We will also in the near future analyse the time spent on talking about the different aspects of the driving questions. We will also analyse in what ways and how the teacher scaffolds the students throughout the work with the learning environment. These results will be published elsewhere in the near future.

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References


Abstract

This paper examines the strength of teacher beliefs about teaching chemistry by setting up an intervention study using teaching modules which are geared to the promotion of scientific and technological literacy. These beliefs relate to the thinking and decision making made by teachers in teaching chemistry and are considered from three perspectives – a personal attitudes, perception of social pressure, and self-efficacy (termed as a perceived ability to enact a belief). Data were gathered before and during the intervention by means of teacher interviews and classroom observations and these were used to identify teacher beliefs as core (both stated and enacted), peripheral (stated but not enacted), or emerging (newly stated beliefs coming from the intervention). Outcomes show that the modules were able to play a role in changing teacher beliefs, but this depended on a range of factors, central to these being the constraints perceived by the teacher such as overloaded curriculum and lack of teaching materials.

Introduction

The achievement of scientific literacy is seen today as a main goal of science education (OECD, 2003). Different interpretations have been used for describing its meaning including both narrower and wider perspectives of this concept (Lauksch, 2000). The teaching-learning approach implemented in the current study is more driven by extended perspective of its meaning, known as the scientific and technological literacy (STL), framework, first initiated within an UNESCO/ICASE conference in 1993 (UNESCO, 1993). Research on the operationalization of teaching for the enhancement of STL has shown that is not easy to change teachers’ thinking and practice (Rannikmäe, 2001).

Reasons why many school reforms have had too little influence on the real classroom practice has been explained by different authors (Lumpe et al., 2000; Bybee, 1993), suggesting that many attempts have actually neglected teachers’ needs, thoughts and beliefs. The teacher, as the key figure and expert in every school improvement, has been seen only as an adaptor of the ideas coming from educators and educational officials (the top-down principle). Several researchers (Bybee, 1993; Haney, Czerniak & Lumpe, 1996; Tobin, Tippin & Gallard, 1994) support the notion that teacher beliefs are precursors to change, playing a critical role in restructuring education. Changing teacher beliefs may be a necessity for developments which promote student learning.

Methodology

This study is ongoing and is being developed in a number of phases.

The main goal of the study described in this paper was to induce change in chemistry teachers’ beliefs towards STL. The goal involves a shift from beliefs based on more traditional teaching styles and having emphasis on eliciting students’ extrinsic interest towards the STL approach, emphasising student centred approaches and students’ intrinsic motivation. The induced change is characterised as going beyond a peripheral change brought
about through an intervention programme to core beliefs indicating true teacher ownership of the STL idea. Core beliefs are defined as those beliefs that are both stated and enacted, whereas the peripheral beliefs are those that are stated, but not operationalised (Haney and McArthur, 2002).

For the first year of the study the goals were to:

1) introduce the STL teaching approach to the participants and familiarise them with teaching approaches related to this, and
2) examine the teachers’ beliefs regarding chemistry teaching and the STL approach.

The following two research questions were posed:

a) Does the intervention programme utilised, in which teachers agreed to participate, play any role in changing teacher beliefs?
b) In what ways does an intervention study, designed using STL modules, enable peripheral beliefs to be converted to core beliefs?

To seek answers these questions, case studies for each of the participants were generated based on interviews and observations. At the beginning of the school year the initial beliefs were identified of the participating teachers, regarding chemistry teaching, differentiating between two types of beliefs: (a) core and (b) peripheral beliefs. The Theory of Planned Behaviour (Ajzen, 2005; Fishbein & Ajzen, 1975) was selected as an additional framework to provide a working model for this study, enabling the researchers to identify and examine an individual’s beliefs and intentions when behaving in a particular fashion. This identified three belief factors: attitude towards a behaviour (AB), subjective norm (SN), and perceived behavioural control (PBC).

The beliefs emerging during the intervention (the beliefs connected to the STL approach) were identified at the end of the school year (labelled as emerging beliefs). The purposeful selection of participants (Patton, 1990) characterized the methodology of the study. The schools in which the three participated teachers taught were situated in one district in northern Estonia. The selection of three participants from the bigger group of chemistry teachers in a given district aimed to insure participation of teachers exhibiting a wide range of positions toward chemistry teaching.

The STL materials used to guide this study were taken from, or were adaptations of modules developed under an ICASE design (Holbrook and Rannikmäe, 1997). These modules feature learning objectives reflecting the need to enhance scientific literacy towards responsible citizenry and covering conceptual chemistry learning, science methods of inquiry, enhancing communication skill and cooperative learning and stressing socio-scientific decision making.

The participants were introduced to the philosophy and the goals of the STL approach. The intervention was conducted for students in the 11th grade. The teachers carried out three modules throughout the school year. Every teacher received individual guidance from the principal researcher before and during the implementation of a particular module.

The following qualitative data gathering instruments were adopted for this study:

1. Semi-structured interviews on teacher’s beliefs were designed to develop an understanding of how each teacher viewed chemistry teaching, as well as what underlying beliefs could impact on their implementation of the STL approach. The semi-structured interview design was developed following the model described by Ajzen and Fishbein (Ajzen, 2005) distinguishing between three belief factors: attitude towards behaviour (AB), subjective norm (SN), and perceived behavioural control (PBC).
Each participant was interviewed at the beginning and at the end of the school year by the first author. The format of the after-intervention interview was also based on the Ajzen and Fishbein’s model (Ajzen, 2005).

2. The first session of the classroom observations, following a non-participative format, were carried out at the beginning of the intervention prior to the introduction of STL ideas. The observation data (collected as detailed field notes) were analyzed and compared with AB teacher belief factors as an outcome of the interview findings in order to identify: a) core beliefs, and b) peripheral beliefs of participating teachers.

A second session of classroom observations was carried out to obtain a better understanding of how STL- modules were adapted and implemented in the classroom.

3. Teachers’ reflective commentaries on the use of the modules, collected in oral format, were recorded and transcribed in order to obtain feedback from the teachers regarding their experiences with the STL modules and about changes they made in module design.

Results and discussion

As a result of the study, a range of different beliefs regarding chemistry teaching was established and categorized. Data from teacher interview transcripts and observation field notes were coded as AB, SN+, SN-, PBC+ and PCB (where the + and – signalled positive or negative beliefs). Also identified were emerging beliefs defined as beliefs that had yet to be fully formulated, but were emerging from the classroom experiences gained through the intervention. They were coded also as AB+, AB-, SN+, SN-, PBC+ and PCB-. Table 1 gives an overview of beliefs categories established by the teacher A.

Amongst the AB beliefs, several core beliefs were found that had, depending on the teacher, more student-centred or teacher-centred character. At the same time, a couple of peripheral beliefs were established which the teachers were not able to put into practice, e.g. the beliefs that chemistry teaching should provide students with possibilities for self-discovery, or beliefs that school chemistry should prepare students for life. The character of peripheral beliefs showed that two of the teachers would have liked to use a more relevant and student centred teaching approach, which in fact they actually used. At the beginning of the intervention, a couple of negative PBC belief factors in common were identified which more or less influenced the teachers’ usual practice: the pressure to cover content, lack of appropriate learning-teaching materials and lack of self-efficacy beliefs in motivating students. The study revealed also that, generally, all teachers were able to implement STL modules in an acceptable way and there was no need for additional pedagogical knowledge.

The results of the last interview with teachers showed that several positive beliefs towards STL emerged: the new approaches increased students’ motivation to learn and changed the teacher’s role in the classroom; it became easier to guide students to learn; modules enabled students’ self-discovery (AB beliefs); the participants felt the support from students and other participants (SN beliefs), and that the project offered appropriate teaching-learning materials (PBC belief).

Additionally, it was recognised by the researchers, that emerging beliefs (beliefs that emerged throughout the intervention) cannot be unambiguously equated with changed core beliefs and there is a need for further research in order to confirm changes in core beliefs (or peripheral beliefs becoming core beliefs) of these chemistry teachers.
Table 1: Example of belief categories established by the teacher A

<table>
<thead>
<tr>
<th>AB beliefs</th>
<th>Peripheral</th>
<th>Individualised approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hands on activities as an illustration of theory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Basic skills</td>
</tr>
<tr>
<td>Core</td>
<td></td>
<td>Variety of learning activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prepare students for life</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Personal relevance</td>
</tr>
<tr>
<td>SN Beliefs</td>
<td>SN⁺: colleagues as a source of teaching ideas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SN⁻: unmotivated students</td>
<td></td>
</tr>
<tr>
<td>PBC beliefs</td>
<td>PBC⁻: lack of time and ability to cover the chemistry curriculum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lack of appropriate learning materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lack of ability to make students learn</td>
<td></td>
</tr>
<tr>
<td>Emerging beliefs</td>
<td>AB⁺: new approach increased students’ motivation to learn, and changed teacher’s role in classroom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>it was easy to make students learn and they were interested in very different things</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AB⁻: the things the students were interested in during the modules were not always connected to chemistry content</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SN⁺: support from students and other participants (for sharing ideas and giving feedback)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PBC⁺: increased self-efficacy belief in motivating students and in formative assessment skills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PBC⁻: lack of equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>demanding assessment system suggested by the project</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions and implications

How far the intervention was able to bring about changes in the teaching was heavily related to the teacher’s beliefs and how these could be developed to outweigh the constraints imposed by the system. The study shows that receiving individual support and having suitable teaching material available can play a positive role in guiding teachers towards implementing peripheral beliefs and thus can play a role in making a paradigm shift from stating a belief and actually putting it into practice in the classroom. The intervention materials gained the support of students and this was seen as a particular positive factor guiding teachers willingness to undertake a challenge.

The initial part of the study revealed, that the teachers held several peripheral beliefs which they were not able to put into practice (see earlier), and they explained this by the existence of different constraints (basically negative PBC and SN factors) which were interpreted as unsatisfied needs: the need for more relevant learning-teaching materials, the need for greater competence, the need for collegial or students’ support, etc. It could be said, that the pilot study met, at least partially, such needs.

As an outcome of the study and from theoretical deliberations, it was decided that the intervention study should meet teacher expressed needs so as to assure more persistent change in teachers’ core beliefs or, to help peripheral beliefs become core beliefs. The approach used was to pose a problem - identifying ways in which it is possible to meet teacher’s needs (in the context of our STL intervention). This constituted the base for developing the format for a second year of the study.
References


Abstract

Pedagogical content knowledge (PCK) is defined as “the particular form of content knowledge that embodies the aspects of content most germane to its teachability” (Shulman, 1986, p. 6). Efforts to move beyond theoretical considerations of PCK depend upon methods for capturing and describing specific examples of PCK. Yet this task is complicated by the nature of PCK itself. This knowledge, like many forms of teacher knowledge, is often tacit, largely because practice does not require its articulation (Loughran, Mulhall, & Berry, 2004). This paper describes a framework for using video to capture aspects of PCK which are visible in one component of teachers’ practice: their use of content in classroom interactions with students. Two separate pilot studies have been conducted to develop and refine the framework reported in this paper. Data for both studies is drawn from the IPN Video Study, which sought to capture a representative sample of German 9th grade physics instruction. Richness, flexibility, and learner-centeredness were identified as characteristics of teachers’ knowledge visible in content-based classroom interactions and, thus, formed the framework for identifying interactions which reflect teachers’ PCK.

Introduction

Consider an accomplished physics teacher and an accomplished physicist. While each must possess detailed knowledge of physics content, the teacher must also know how to translate that content knowledge into meaningful instruction for his students. This specialized knowledge, unique to teachers of particular content, has been labeled pedagogical content knowledge (PCK) and is defined as “the particular form of content knowledge that embodies the aspects of content most germane to its teachability” (Shulman, 1986, p. 9). At the core of all characterizations of this construct are Shulman’s two key components: knowledge of student learning difficulties and knowledge of instructional representations (van Driel, Verloop, & de Vos, 1998). These can be thought to underlie teachers’ instructional decision-making – from planning examples and other ways of presenting content to students to interacting with them in the midst of classroom instruction (Borko, Roberts, & Shavelson, 2008; Bromme, 1995; Shulman, 1987).
Rationale

As Hashweh (2005) noted, theoretical discussions of PCK may be at an impasse. Efforts to move beyond theoretical considerations of PCK depend upon methods for capturing and describing specific examples of PCK. Yet, this task is complicated by the nature of PCK itself. This knowledge – like many forms of teacher knowledge – is difficult to articulate. PCK – as knowledge which influences practice – is often tacit, largely because practice does not require its articulation (Loughran, Mulhall, & Berry, 2004), and teachers may not possess a shared language with which to communicate this knowledge to others (Baxter & Lederman, 1999).

Video provides a promising approach to capturing some aspects of teachers’ PCK. While acknowledging the argument that observation of classroom events cannot fully capture a teacher’s PCK (Baxter & Lederman, 1999), we agree with the claim that PCK may be recognizable in the ways in which a particular topic is taught (Loughran, et al., 2004) and are interested in exploring what aspects of PCK could be captured through videos of classroom practice. We believe that this is consistent with Shulman’s (1987) emphasis on the practical importance of PCK, that its utility “lies in its value for judgment and action” (p.14) and, thus, we were interested in examining PCK in situ.

We sought to explore the aspects of PCK visible in teachers’ practice. However, PCK is multi-faceted, encompassing many aspects of teaching practice and the thinking surrounding that practice. We chose to concentrate on teachers’ content-based interactions with students as a particularly key instantiation of their PCK. Because PCK is thought to be or to result from the transformation of other types of knowledge – particularly content knowledge (e.g., Geddis, Onslow, Beynon, & Oesch, 1993; Magnusson, Krajcik, & Borko, 1999; Shulman 1987) – content-based interactions seem to be a rich arena in which to watch PCK play out, capturing both planned instruction and unplanned responses to students’ in-class contributions.

Our research was guided by the following question: What aspects of PCK are visible in the ways in which teachers use content in classroom interactions with students? To answer this question, we developed a framework to describe teachers’ content-based interactions with students during classroom instruction. In the sections that follow, we describe two separate pilot studies which have been conducted to develop and refine our preliminary framework; present and discuss the resulting framework; and reflect upon the framework and consider implications for future work.

Methods

Data Sources

Two separate pilot studies have been conducted to develop and refine the framework reported in this paper. Data for both studies is drawn from the IPN Video Study (Seidel, Prenzel, & Kobarg, 2005), which sought to capture a representative sample of German 9th grade physics instruction. During the 2002-2003 school year, a double lesson of physics instruction (approximately 80-90 minutes in total) on either optics or mechanics was videotaped in each classroom, according to standardized guidelines (Seidel et al., 2005).

As part of the IPN Video Study, pre-/post-measures of students’ knowledge and interest were administered at the beginning and end of the school year (see Seidel et al. (2005) for technical details). The two classrooms in Study 1 (topic = optics) were selected based upon contrasting patterns of students’ knowledge and interest development. As compared to the other teachers in the IPN sample, one teacher’s students had high gains in knowledge and interest, while the other’s students had low gains in knowledge and a decrease in interest. The two classrooms in Study 2 (topic = mechanics) were selected to represent contrasting gains in students’ knowledge. Lessons in all eight classrooms followed a similar structure, including whole class discussions and short hands-on investigations.

3 The expanded version of the paper describes the evolution of the framework to its current form and includes detailed examples from both pilot studies as illustrations of the framework components.
Data Analysis

As part of the IPN Video Study, transcripts of all classroom videos were created in Videograph © (Rimmele, 2002). For the two pilot studies, all transcripts were translated into English. Version 4.1 of Videograph © (Rimmele, 2007) was used to view all videos (and associated transcripts) in the two pilot studies. Coding of the videos was conducted without knowledge of why the teachers had been chosen (i.e., without student data).

**Study 1: Optics**

The videos were initially viewed by the first author, and impressions related to each teacher’s use of content knowledge were recorded. Next, specific examples were identified in each video, reflecting either positively or negatively on the teacher’s own knowledge. A set of codes was developed to characterize the classroom interactions in terms of the evidence they provided for characteristics of teachers’ knowledge. Three broad characteristics were identified: 1) flexible, 2) rich, and 3) learner-centered. Finally, event sampling and coding was used to identify and describe segments of video which reflected on teachers’ knowledge, according to these characteristics. The first author coded the videos for both teachers; expert validation was used to establish reliable coding.

**Study 2: Mechanics**

Two researchers (the first and second authors) viewed and coded all of the videos; event sampling and coding was conducted independently, with subsequent discussions to reach consensus about any discrepancies. Both researchers identified video clips which reflected positively or negatively on the teacher’s knowledge. Where possible, the coding scheme developed in Study 1 was applied to these examples, noting instances in which the original coding scheme did not adequately capture the interactions. These notes were used to refine and add to the original coding scheme. Study 2 videos were then recoded, using the new coding scheme.

**Results**

The current framework (Figure 1) identifies three characteristics of teacher knowledge which may be reflected in content-based classroom interactions. For each characteristic, we identified types of interactions which we believe provide evidence for that aspect of teachers’ knowledge. For each type of interaction, we created a scale, which was used to rate the extent to which a particular interaction provided evidence for the teachers’ own knowledge having the associated characteristic. A single interaction could provide evidence for multiple characteristics.

Flexible

*Flexible* knowledge is indicated by teachers’ ability to recognize and utilize multiple ways of expressing a given content idea, as well as the ability to respond to students’ incorrect or unexpected content-based contributions. The framework identifies three types of classroom interaction which provide evidence with respect to this characteristic: 1) responses to students’ on-topic but unconventionally-worded or slightly incorrect contributions (*Recognizing*); 2) responses to students’ off-topic or incorrect contributions (*Responding*); 3) responses to students’ inability to answer a question posed by the teacher (*Wording*). Although a teacher may draw upon flexible knowledge in planning how to respond to common student ideas, this characteristic primarily captures “on the fly” use of knowledge.
Recognizing

As shown in Table 1, Recognizing interactions were coded using a 5-point scale. At the highest level (2), the teacher recognizes the student’s contribution and explicitly connects the student’s words with a more conventionally-worded or correct statement of the idea. In order to do this, the teacher must be listening carefully to students’ words. He/she must then be able to both recognize the physics idea that the student has expressed and make a meaningful connection between the student’s idea and the physics idea explicit for the class.

Table 1. 5-point scale used to code Recognizing interactions (indicating the Flexible characteristic).

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The teacher recognizes the student’s unconventionally-worded or slightly-incorrect contribution and explicitly connects the student’s words with a more conventionally-worded or correct statement.</td>
</tr>
<tr>
<td>1</td>
<td>The teacher identifies the student’s unconventionally-worded or slightly-incorrect contribution with a scientific idea. If rewording takes place, the teacher is explicit about differences between his/her formulation and that of the student.</td>
</tr>
<tr>
<td>0</td>
<td>The teacher identifies the student’s unconventionally-worded or slightly-incorrect contribution with a scientific idea; however, differences between the teacher’s and student’s formulations are unclear.</td>
</tr>
<tr>
<td>-1</td>
<td>The teacher’s response to the student’s correct (although perhaps unconventionally-worded) or slightly-incorrect contribution indicates some lack of recognition or mis-understanding of the student’s words.</td>
</tr>
<tr>
<td>-2</td>
<td>The teacher’s response to the student’s correct (although perhaps unconventionally-worded) or slightly-incorrect contribution has the potential to promote student misconceptions or confusions.</td>
</tr>
</tbody>
</table>

The intermediate level (0) is the lowest at which the teacher still recognizes student contributions; however, at this level, the recognition glosses over differences between the student’s contribution and more scientific formulations. The teacher may acknowledge the student’s response, while insisting upon a particular alternative wording, or he/she may reword the student’s slightly incorrect response without acknowledging that this has been done. At the next lower level (-1), the teacher does not seem to fully recognize the student’s correct (although perhaps unconventionally-worded) or slightly-incorrect contribution. In sharp contrast to the two highest levels, interactions at this level seemed to indicate a lack of careful attention to students’ words. Often, these interactions seemed to occur because the teacher was looking for particular responses to his/her questions. Finally, in the lowest level (-2), the teacher “mis-recognizes” student contributions and/or responds to student contributions in confusing or incorrect ways. Interactions at this level have the potential to contribute to student misconceptions or confusions.
**Responding**

As shown in Table 2, Responding interactions were coded using a 5-point scale. The coding scheme for the Responding category was designed to mirror that for the Recognizing category. While both categories involve in-the-moment responses to student contributions, interactions associated with the Responding category were more unpredictable than those associated with the Recognizing category.

At the highest level (2), the teacher’s response builds upon the student’s contribution and promotes understanding of relevant content. As with the highest level of the Recognizing category, this requires teachers to listen carefully to student’s words; however, because student contributions in this category are more unexpected, the teacher must think more flexibly on the spot. At the intermediate level (0), the teacher responds to a student’s off-topic or incorrect contribution in a way that, although recognizing the student’s contribution, does not clearly connect his/her words with relevant science content. At the lower levels in this category, the teacher struggles to respond to students’ off-topic or incorrect contributions. The two lowest levels (-1 and -2) are distinguished by the potential of the teacher’s response to contribute to student misconceptions or confusion.

Table 2. 5-point scale used to code Responding interactions (indicating the Flexible characteristic).

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The teacher responds to the student’s off-topic or incorrect contribution in a way which builds upon the student’s words and promotes understanding of relevant content.</td>
</tr>
<tr>
<td>1</td>
<td>The teacher responds to the student’s off-topic or incorrect contribution in a way which is clear and connects the student’s contribution with relevant content.</td>
</tr>
<tr>
<td>0</td>
<td>The teacher recognizes the student’s off-topic or incorrect contribution but does not clearly connect his/her words with relevant science content.</td>
</tr>
<tr>
<td>-1</td>
<td>The teacher does not recognize the student’s off-topic or incorrect contribution; the student’s words are not incorporated into the class discussion in a meaningful way.</td>
</tr>
<tr>
<td>-2</td>
<td>The teacher responds to the student’s off-topic or incorrect contribution in a way that has the potential to promote student misconceptions or confusions.</td>
</tr>
</tbody>
</table>

**Wording**

As shown in Table 3, Wording interactions were coded using a 4-point scale. Subcodes were used to indicate particular types of interactions. This category reflects the teacher’s ability to respond to situations in which students are unable to provide satisfactory answers to questions posed during class discussion and is intended to capture the teacher’s capacity to express questions in alternative ways. In addition to the main scale for this category, two additional scales were used to provide contextual information about the interaction, describing what happened immediately before (the original question) and immediately after (the student’s response) the rewording event.4

Table 3. 4-Point scale used to code Wording interactions (indicating the Flexible characteristic).

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The teacher rewords his/her initial question with content-based scaffolding.</td>
</tr>
<tr>
<td>0</td>
<td>The teacher rewords his/her initial question without content-based scaffolding.</td>
</tr>
<tr>
<td>-1</td>
<td>The teacher does not reword his/her initial question, despite indications of student confusion</td>
</tr>
<tr>
<td>-2</td>
<td>The teacher rewords his/her initial question, but the rewording changes the question and/or has the potential to make students more confused and/or to promote misconceptions.</td>
</tr>
</tbody>
</table>

At the highest level (1), the teacher rewords his/her initial question with content-based scaffolding, drawing upon his/her own flexible understanding of the content to help students to engage with the substance of the question. At the next highest level (0), the teacher asks his/her question in a different way, but these rewordings do not draw upon any specific content knowledge. At Level -1 the teacher does not reword questions, despite

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4 Due to space limitations, the subcodes and additional scales are not included here; they are available in the expanded version of the paper.
indications of student confusion (e.g., no responses to the original question or only incorrect responses to the original question). The framework distinguishes three ways this may occur, all of which may be appropriate under certain circumstances. However, repeated interactions at this level may indicate a difficulty in rephrasing questions to make them more comprehensible to students. Finally, at the lowest level (-2), the teacher rewords his/her question, but the rewording either simplifies the question (such that students no longer have to engage with the content of the question) or has the potential to make students more confused and/or to promote misconceptions.

Rich

The interactions associated with the Rich characteristic focus on the connections that the teacher makes in order to strengthen students’ understanding of targeted content. We identified three types of connections: those between content and 1) illustrative examples (Examples), 2) representations (such as graphs, data tables, schematic drawings, experimental set-ups) (Representations), and 3) other science principles (Science Principles). Here, we use a relatively loose definition of “interactions”, including scenarios in which the teacher is presenting information and the students are listening. In contrast to the Flexible characteristic, interactions which indicated the Rich characteristic were more likely to be planned in advance.

Our codes for this characteristic focus primarily on the potential of the interaction to advance student understanding of the targeted content. The 5-point coding schemes for all three types of interaction (Table 4) were designed to mirror each other, each reflecting this same focus. To illustrate the commonalities across the different interactions in this category, this section is organized by level, rather than by type of interaction.

Table 4. 5-point scale used to code interactions in the Rich category.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Examples</th>
<th>Representations</th>
<th>Science Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The connection between the targeted content and the example/representation/other science principle is deep and has the potential to advance students’ understanding of the targeted content.</td>
<td>The connection between the targeted content and the example/representation/other science principle is deep and has the potential to advance students’ understanding of the targeted content.</td>
<td>The connection between the targeted content and the example/representation/other science principle is deep and has the potential to advance students’ understanding of the targeted content.</td>
<td>The teacher misses an opportunity to make a connection to a science principle which has been introduced into the class discussion.</td>
</tr>
<tr>
<td>1</td>
<td>The connection between the targeted content and the example/representation/other science principle is clear.</td>
<td>The connection between the targeted content and the example/representation/other science principle is clear.</td>
<td>The connection between the targeted content and the example/representation/other science principle is clear.</td>
<td>The connection between the targeted content and the example/representation/other science principle is clear.</td>
</tr>
<tr>
<td>0</td>
<td>The connection between the targeted content and the example/representation/other science principle is superficial and/or unclear.</td>
<td>The connection between the targeted content and the example/representation/other science principle is superficial and/or unclear.</td>
<td>The connection between the targeted content and the example/representation/other science principle is superficial and/or unclear.</td>
<td>The connection between the targeted content and the example/representation/other science principle is superficial and/or unclear.</td>
</tr>
<tr>
<td>-1</td>
<td>The illustrative example does not actually embody the targeted content.</td>
<td>The illustrative example does not actually embody the targeted content.</td>
<td>The illustrative example does not actually embody the targeted content.</td>
<td>The illustrative example does not actually embody the targeted content.</td>
</tr>
<tr>
<td>-2</td>
<td>The connection between the targeted content and the example/representation/other science principle is confusing, with the potential to promote or reinforce misconceptions.</td>
<td>The connection between the targeted content and the example/representation/other science principle is confusing, with the potential to promote or reinforce misconceptions.</td>
<td>The connection between the targeted content and the example/representation/other science principle is confusing, with the potential to promote or reinforce misconceptions.</td>
<td>The connection between the targeted content and the example/representation/other science principle is confusing, with the potential to promote or reinforce misconceptions.</td>
</tr>
</tbody>
</table>

At the highest level (2), the connection is deep and has the potential to advance students’ understanding of the relevant content. In Examples interactions, teachers used a wide variety of real-life examples to deepen students’ understanding of relevant content. At this level, teachers did not just introduce these examples, but engaged students in consideration of the content with respect to these examples. Level (1) interactions involve more straightforward connections and less discussion than interactions at Level 2. At the intermediate level (0), the connection is superficial and/or unclear. At this level, Examples may be connected to the topic, rather than to any specific content. These discussions often seemed designed to motivate student interest, rather than deepening their understanding of particular ideas.
The lower levels of this category (Levels -1 and -2) were relatively rare; however, they describe important types of interactions. Level -1 includes a variety of different interactions. While Level -1 interactions might be confusing, those at Level -2 were likely to result in students being taught incorrect ideas. At Level -2, the connection is confusing, with the potential to promote or reinforce misconceptions. Failed demonstrations are included here.

Learner-Centered

*Learner-Centered* representations of content indicate consideration of content from the student’s perspective. We expect this category to be only partially visible in videos of classroom practice. We expect teachers to use learner-centered representations of content in the background, particularly to plan instruction which is sensitive to typical student learning difficulties and appropriate sequencing of content ideas. However, in both studies, we identified important manifestations of this category in our samples.

In Study 1, we identified evidence – both positive and negative – for teachers’ awareness of what content students find to be difficult and of appropriate sequencing of particular pieces of content (i.e., which ideas are prerequisite to others) (*Awareness*). These interactions involved explicit statements about the difficulty of particular content and/or about instructional decisions based upon awareness of student learning. Because no such interactions were identified in Study 2, our description of this type of interaction was not refined; however, we retained this type of interaction in our framework, in case it is visible in other videos of classroom practice.

In Study 2, we identified more subtle indicators of teachers’ awareness of student learning difficulties, particularly surrounding well-documented student misconceptions (*Misconceptions*). We developed a 5-point scale (shown in Table 5) to describe interactions involving common misconceptions.

Table 5. 5-point scale used to code *Misconceptions* interactions (indicating the Learner-Centered characteristic).

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The teacher helps students to understand both why a misconception is incorrect and why the scientific conception is correct.</td>
</tr>
<tr>
<td>1</td>
<td>The teacher points out an incorrect idea (a misconception) and provides the scientific conception without further attempts to resolve the misconception.</td>
</tr>
<tr>
<td>0</td>
<td>The teacher points out an incorrect idea (a misconception), but does not provide a scientific conception to replace it.</td>
</tr>
<tr>
<td>-1</td>
<td>The teacher misses an opportunity to address a student misconception or presents material in a confusing way, which fails to address an underlying misconception.</td>
</tr>
<tr>
<td>-2</td>
<td>The teacher’s instruction promotes or reinforces misconceptions.</td>
</tr>
</tbody>
</table>

At the highest level (2), *Misconceptions* interactions help students to understand both why the misconception is incorrect and why the scientific conception is correct. At the next highest level (1), teachers point out an incorrect idea (a misconception) and provide the correct conception, without further attempts to help students to resolve differences between the two. At the intermediate level (0), the teacher points out an incorrect idea (a misconception), but does not attempt to provide an alternative conception to replace it.

At the lower levels (-1 and -2), teachers may not recognize common student misconceptions. Interactions at the higher of these two levels (-1) represent missed opportunities to address student misconceptions. The teacher might gloss over a student statement representing a misconception. Often, this occurred when the teacher accepted a student statement including a misconception but reworded it to the correct conception without comment. Finally, at the lowest level (-2), the teacher’s instruction promotes or reinforces misconceptions. As with other categories in our framework, Level -2 is distinguished from Level -1 by increased potential to negatively impact student learning.
Conclusions and Implications

Consideration of the Relationship between the Current Framework and PCK

Thus far, this paper has reported on a framework for describing teachers’ content-based interactions with students during classroom instruction. However, as the intent of our research was to capture aspects of PCK in action, it is important to return to the construct of PCK and to evaluate the extent to which the framework reflects aspects of PCK. This task is facilitated by our framing of the content-based interactions in terms of evidence for characteristics of teachers’ own knowledge.

The Flexible category is consistent with a view of PCK that emphasizes its use in practice, what some have called “PCK-in-action” (e.g., Janík & Miková, 2006). This follows directly from a view of PCK itself as being knowledge in action (e.g., Appleton, 2002; Seymour & Lehrer, 2006). As mentioned above, Shulman emphasized the practical nature of PCK, and other researchers have defined PCK in terms of its use (e.g., Magnusson, 1991; Fernández-Balboa & Stiehl, 1995; Veal, Tippins, & Bell, 1999).

The Rich category can be thought to correspond to knowledge of instructional representations. Shulman’s (1986) original formulation of PCK includes the following description:

… the most useful forms of representation of… ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations-in a word, the ways of representing and formulating the subject that make it comprehensible to others. (p. 9)

Shulman’s use of “representation” may be thought to encompass both Examples and Representations interactions. Magnusson et al. (1999) have interpreted representations to be “illustrations, examples, models, or analogies”, which aligns well with Examples types of interactions. These might be thought to be ways of illustrating a content idea. In contrast, Representations interactions might be thought to be ways of representing a content idea, using representational tools of the discipline. This latter interpretation seems consistent with the way that mathematics educators talk about representations (e.g., National Council of Teachers of Mathematics (2000)). To support the inclusion of Science Principles interactions, we return to Shulman, who pointed to the importance of teachers’ understanding of how a particular idea “relates to other ideas within the same subject area and to ideas in other subjects as well” (1987, p. 14). The importance of connections across ideas is echoed by others writing about PCK (e.g., Gess-Newsome, 1999; Grossman, Wilson, & Shulman, 1989; Hashweh, 1987).

The Learner-Centered category can be thought to correspond to knowledge of student learning difficulties. Shulman’s (1986) original definition stated, “Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult” (p. 9). Teachers’ knowledge of how to sequence content is explicitly included in a number of more detailed explorations of PCK (e.g., Magnusson, et al., 1999; Smith & Neale, 1989), while others include recognition of factors influencing the complexity of various instructional tools (e.g., Clermont, Borko, & Krajcik, 1994). Both of these ideas are reflected in the Awareness category, developed in Study 1. A number of researchers (e.g., Carpenter, Fennema, Peterson, & Carey, 1998; Grossman, 1990; Marks, 1990; Stump, 2001; Veal & McKinster, 1999; Wilson, Shulman, & Richert, 1987) explicitly include knowledge of student misconceptions in their definitions for PCK. This corresponds to the Misconceptions category, introduced in Study 2.

Implications & Future Research Directions

Our framework for examining video evidence of teachers’ content-based classroom interactions has been applied to videos of eight German teachers’ instruction on two topics in the 9th grade physics curriculum. Although these classrooms were selected to represent contrasting gains in student achievement, they were also purposefully selected to represent similar classroom structure (whole class discussion mixed with short hands-on activities). Thus, they do not represent the full range of classrooms in the IPN Video Study; nor was the IPN Video Study designed...
to capture science instruction broadly. It is possible that instructional styles in other contexts may yield different evidence for teachers' PCK in their classroom content-based interactions with students.

In moving from consideration of the classrooms in Study 1 to those in Study 2, we were struck by the (perhaps obvious) dependency of our framework upon interactions – opportunities for teachers to listen and respond to student contributions. There was much less student talk in the classrooms in Study 2, and, thus, much less evidence related to teachers’ content-based interactions with their students. We wondered whether a lack of evidence could be interpreted as a lack of PCK or merely an indication of a different style of teaching. Clearly, interview data might help to resolve this dilemma; however, as one of our goals was to explore the possibility of using a classroom-based framework for aspects of PCK, it seems important to note this observed limitation of our approach.

Despite these limitations, we believe that the framework captures some important aspects of teachers’ content-based interactions with their students, which should be applicable to classrooms and topics beyond those in the two pilot studies. Further work is needed to test the generalizability of this framework. We believe that there are several important possible applications for this work. Most fundamentally, the framework provides a lens for examining classroom practice. This has implications for both research and teacher development efforts. First, the framework may help to answer calls for specific descriptions of PCK for particular science topics (e.g., Geddis, et al., 1993; Magnusson, et al., 1999; van Driel, et al., 1998). Such descriptions may help to fill a perceived need for re-conceptualization of the construct of PCK, emphasizing its topic-specific (Hashweh, 2005), contextualized, and practical (e.g., Cochran, DeRuiter, & King, 1993; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001) nature. Specific examples of PCK are required to more clearly communicate researchers’ ideas about this construct to practitioners (both teacher educators and teachers themselves). Second, the framework may serve as a means for capturing aspects of PCK in ways which could be used in studies of PCK – for example, examining the relationship between PCK and student learning (e.g., Alonzo, Kobarg, & Seidel, 2008). Because the framework provides a means of identifying and evaluating components of PCK, it might also be useful for evaluating teacher education programs; one might imagine examining evidence for the aspects of PCK contained in our framework before and after a particular teacher education course or professional development program. Finally, the framework may help to organize teacher education targeting PCK. For example, content-based interactions reflecting various levels of PCK may be selected for viewing and discussion as part of video-based teacher professional development.

References


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5 The proportion of student talk in the two classrooms in Study 1 was high compared to other classrooms in the IPN Video Study (about 40% student statements); there was less student talk in the six classrooms in Study 2 (5-29% student statements).
Contemporary Science Education Research: TEACHING:


ANALOGIES AS DIDACTIC RESOURCES TO INTRODUCE A STS APPROACH IN PHYSICS TEACHING

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Abstract

It is recurrent among science educators the certainty of the importance to establish connections between the systemized scientific knowledge in classroom with the reality of the student. On the other hand, studies that privilege the role of language in science education consider that one of the ways to facilitate the communication in classroom, in order to make the scientific knowledge understandable, is through the use of analogies and other language figures. We report here partial results of a broader study that investigates the role of language in the graduation of prospective High School Physics teachers. This study investigates, at the same time, language questions present in activities of teachers' graduation and questions about the inclusion of relations STS in classroom. One of the questions that we search to answer in this research is: Can the use of analogies as didactic resources facilitates the understanding of scientific concepts in technological applications of daily use by the student and, thus, contributes for a scientific and technological literacy that help them for the comprehension of the world? This research was carried out with a sample of physics student teachers of a public university in São Paulo, Brazil, and data were constituted during the activities of a course considered essential in the initial teachers' graduation: Methodology and Practice of Physics Teaching. We perceived that the explanations using analogies as didactic resources in classroom could make possible the understanding of the scientific knowledge present in technological applications, since carefully used. Moreover, we detected the necessity of inquiries concerning the connections between the systemized knowledge acquired in the school with subjects present in students' reality.

Background, Aims and Framework

It is recurrent among Science Educators the certainty of the importance to establish connections between the systemized scientific knowledge in classroom with the reality of the student. According to Cobern, Gibson and Underwood (1995), the school seems to separate the knowledge and the students' abilities. That is, usually teachers do not instigate students to make connections between the systemized knowledge acquired in the school with subjects of their daily life. For these authors, teachers should provide to the students the vision that Science, like others fields of knowledge is part of their world and it cannot be taught from fragmentized contents, dissociated of their reality.

Some researchers, like Bybee (1991) and Fullick (1992), with the intention to deep inquiries on this subject, have focused their studies in teachers’ background about practices involving the relations between Science, Technology and Society (STS). Hofstein, Aikenhead and Riquarts (1988), emphasize the importance to contemplate discussions about these STS relations during scientific contents teaching in the authentic context of their technological and social environment, in which the students integrate the scientific knowledge with the technology and its use and impact in their daily experiences.

¹ Support: FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo
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On the other hand, studies that privilege the role of language in education consider that one of the ways to facilitate the communication in classroom and become the scientific knowledge more comprehensible is by means of using analogies and other language figures (HARRISON and TREAGUST, 1993; THIELE and TREAGUST, 1995; OLIVA, 2008). Therefore, the role of language in teaching and learning has been more and more privileged in Science Education research (MARTINS, OGBORN and KRESS, 1999).

Martins, Ogborn and Kress (1999) understand that the knowledge not only suffers many changes until arrives to school, but it is also continuously transformed in the school. The communication of scientific knowledge in the classroom through explanations involves to comprehend the content of these explanations and to be able to communicate this content in an effective way. We can say that the analogies contribute for science education in the way they stimulate the creativity and imagination of the students and invoke the called “mental images” about concepts considered abstract. This analogies power of “visualization” - important for the concepts learning - can be extended with an illustration of the analogous domain as Thiele and Treagust (1995) show.

It is important to point out that the teachers’ undergraduate program new pedagogical project, in which the student teachers of this research sample are being graduated (called “Licenciatura” in Brazil), came into effect from a curriculum reorganization concluded in 2005 (CAMARGO, 2007). This new curriculum has as conducting line the relations between Science, Technology, Society and Environment (STSE), that is, in all courses of the curriculum, the relations STSE must be present. The purpose is the preparation of teachers, since their initial formation, compromised with the necessity of these discussions to assist in the serious environment problems present in the country and the world.

Therefore, this study investigates, at the same time, the use of language in teachers’ classrooms activities and the inclusion of relations STSE in classroom. It intends: a) Consider all the process in which the prospective teacher is inserted and, beyond that, to analyze and identify viabilities and difficulties of them in their classroom practices; b) Evaluate the educational practice of the student-teachers, to verify the transposition of reference knowledge to the knowledge to be taught; c) Investigate the use of language (explanations, analogies etc.) by the student-teachers in physics teaching activities developed in the training period. For example: one of the questions that we wish to answer in this particular research is: Can the use of analogies as didactic resources facilitates the understanding of scientific concepts present in technological applications of daily use by students and thus, contribute for a scientific and technological literacy, in order to help them to comprehend their world?

Analogies as Scientific Explanations

The school communication, specifically in natural sciences, finds a series of difficulties. Many authors have shown the importance of language, and, particularly the explanation, in the teaching and learning of science. We emphasized, as one of them, the presence of an excellent space between the common language and the scientific language, also called “erudite scientific language” as Galagovsky and Adúriz-Bravo (2001) point it. In accordance with these authors, science learning implies, before everything, learning to work with the language.

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Science, Technology and Society in Science Teaching

Vieira and Vieira (2005) point the importance of socio-scientific of recognized relevance subjects approaches in the classrooms, since they allow giving meaning and making them more understandable to the students and do not allow to establish them like inert knowledge. Moreover, the approaching of socio-scientific problems in a concrete way allows, for the motivation and reflection that they raises, to understand better the role of Science in the society and, also, the way the society influences the Science and Technology objects of study.

According to Aikenhead (1994), the benefits in introduction a STS approach in Science lessons are real and consistent, since among other things, they increase students scientific literacy, promote their interest for Science, help the students to improve the critical spirit, the logical thought, and decision-making.

According to Vieira and Vieira (2004), to teach Science with a STS orientation and with intention to approach the phenomena in a way that relates science with the student technological and social world, is widely defended. Specifically in the case of Physics, Moreira (2000) emphasizes that, according to the New Brazilian National High School Curriculum Parameters (PCN), which set out the competences and abilities to be developed by physics teaching, the orientations about questions involving STS would allow “to understand the Physics presents in the existential world and within the equipments and technological procedures; how devices works [...] which means, therefore, teaching Physics for the citizenship; a meaningful Physics” (p. 98).

Methodological aspects of the research

This research was performed with a sample of 23 prospective High School Physics teachers in a public university, from São Paulo State, Brazil. Data were constituted through a semester, during the development of activities of a supervised teacher-training period, occurred at the end of the program curriculum. These activities were an integrant part of one of the subjects present in the undergraduate physics curriculum, considered essential to the teachers’ initial formation: the Methodology and Practice of Physics Teaching. The related activities had as focus the teaching classes training in a public High School. Thus, the student teachers were requested to plan and teach a course (about 60 hours) for High School students. The course was entitled by them as “The other side of Physics”, and included seven modules: Mechanics, Thermology, Optics, Electricity, Electromagnetism, Modern and Contemporary Physics, and Introductory Astronomy.

Each teaching module was prepared and taught for a different group of student teachers. These modules were developed weekly, on Mondays and Tuesdays, in the evening period, from 7:00 to 11:00 p.m. Each group made use of four classes (a total of eight hours) to work the chosen topics. Around 30 first and second years High School students were enrolled in the course. The classes were scheduled in the evening period, in order that these activities had no interference in their other regular High School classes, which were going in the morning. All the course lessons were filmed and transcribed afterwards, so that the researchers could analyze them weekly.

The course had as main goal to provide to the High School students, as well as to the prospective teachers, an alternative view of the teaching and learning processes. For that, professor requested the student to emphasize in theirs classes a dialogical approach, the problematization of the contents and the incorporation of physics teaching recent research outcomes.

Theses subjects had already been studied and argued in the previous semester, when their teaching modules were planned. As recent research outcomes, they had to take into account approaches that privileged: the insertion of History and Philosophy of Science for teaching; pupils’ spontaneous or alternative conceptions; the insertion of topics of Modern Physics and their link with the relations among Science, Technology and Society and to the students’ daily life.
We will consider below, in this paper, some teaching episodes related to Electromagnetism contents, worked under a STS perspective, where appeared analogies as possible didactic facilitator resource to understanding contents and their applications. In relation to the technological applications worked in the course, we will report one only of the cases: the magnetic resonance. Ribeiro (2000) points that the magnetic phenomena are always used in the development of new technologies like Electronics, Computing, and Medicine. According to this author, even not receiving a real attention in teachings processes, magnetism is always present in our daily lives.

Discussion and some results

The student teachers who taught this module stressed in their speech that the subject STS was introduced in the Electromagnetism module “with the main purpose to emphasize the importance that the magnetic materials plays in the technological applications of the Magnetism”. The literature points that the introduction of questions related to STS is of great importance, as does Holton (1979), when speaking about curriculum innovations. This author argues that one should have to set at least a minimum of discussion about the social impact of science and technology through the educational materials used in Science classes.

But, as all curriculum innovation can bring difficulty, the future high school physics teachers pointed that the introduction of STS questions brought a “great difficulty that [...] was to establish, of a well qualitative form, concepts like magnetic momentum and spin, since to transpose such concepts of a complex nature and essentially of a quantum order for students of High School, anyway, it was very problematic. However, the necessity to define these concepts reflected on the subsequent comprehension of the three topics to be taught” (Magnetic Resonance was one of them). As we can perceive, the student-teachers’ preoccupation was with the learning about concepts considered extremely complex, but that were of basic importance for the understanding of how work some applications involving these concepts: “with the help of slides with figures and analogies the magnetic dipole, magnetic moment and spin concepts could be approached”.

We emphasize below some dialogues occurred in classroom, in which we can perceive the use of analogies in the subjects’ approaching:

Student teacher: [...] spin is an elementary particles’ property of essentially quantum nature. Theoretically speaking, it would not have classical analogous that we can close the eye and imagine how would be this spin motion, of this particle [...] but a not so correct analogy, but that one can make, is to consider this electron turning around its own axis. This would be the spin. In addition, this fact, which it turns around its own axis, goes, like this [...] I do not know the correct one, too [...] but it goes to point with a force to up or down, perpendicular to its spinning motion [...] like the Earth was there [...] and its axis, that small arrow. How one see in Chemistry, also, set the spin there, as being one small arrow up, small arrow down, right?

High School Student: How is the upwards or downwards spin defined?

Student teacher: Here, in this case, it can be the g sense… depends much of… (he is insecure in his answer)… you know… if it is free, if the particle is free, depends on if you take an axis there and it is spinning, you will have a moment of a intrinsic dipole there, an intrinsic magnetic moment. This moment is called spin… it would be a force, would be a property. Look, like… that in Physics is a concept very sophisticated and we try to do some approaches, try to simplify, to approach here to you. Then… thus, basically, what you are going to need knowing is that spin up, it goes to exert a force up, spin down, a force to down.

The student teacher attempts to use analogy made him feel satisfied and he thought that his explanation was satisfactory and a solution to the complexity in explaining the spin concept, but that did not happen, as we could see afterwards, with the prompt student question. At the same time, he tries to retake the explanation, but the introduction of new terms as “intrinsic magnetic moment” makes the explanation more difficult to understand. Moreover, the student teacher demonstrates total insecurity in the domain of the content, when he mentions: “I also don’t know the correct one”. According to Fischler and Lichtfeldt (1992), the learning of concepts related to Modern and Contemporary Physics becomes difficult because the teaching, frequently, uses classic analogies.
Therefore, the preoccupation of the future teacher in searching classic analogy would not be synonymous of learning for the students. Menezes (2005) uses analogies to describe the spin such as: "elementary magnets, called spins, as if the particles were micro-whirlwind of charge spinning around themselves (p. 105) [...] the electrons, like a top that spins over itself, have an intrinsic angular moment, its spin, that can assume two orientations"(p. 158).

We know that the use of analogies requires all attention; otherwise, it can turn the concept much more complex if the student does not have references in their cognitive structure that can be analogically related with scientific concepts learning one wants to reach. In the sequence of the lesson, the student teacher explains what magnetic resonance is and mentions that the concepts that they (High School students) would need to understand, already "were clearly supported into the concepts previously defined." As we could notice above, even the concept was worked, still there is a doubt whether it was clearly defined or not, since the future teacher finishes the explanation about the concept in an insecure way: “Then… thus, basically, what you are going to need to know is that spin to up, exerts a force to up, spin to down, a force to down”.

Student teacher: [...] magnetic resonance is an extremely quantum name, that is, it is closely connected to the spins [...] And the magnetic resonance, it provides images generation [...] To study this phenomenon one need to catch a sample, put it immersed in a very strong external magnetic field, and this sample will acquire a certain magnetization, due to the alignments of those spins, those small arrows. Then it is going to acquire a certain magnetic property, with all those properties that we have already studied, and at the beginning, I believe, it is already well known, isn’t it? It is [...] one has the possibility [...] as we had seen, depending on their material, to line themselves with a parallel or ante parallel field: spins in the direction of the field or spins in the field ante parallel direction. It is what it is done here... In the magnetic resonance of image, they are going to oscillate [...] the field very lightly. Then you are going to have a radiofrequency pulse of oscillation. And what’s going on with these spins? With these atoms and electrons are spinning there? They are going to acquire certain energy, aren’t they? Here the spins are disordered and at random [...] And here, the spins are aligned with the field [...] Here is an equipment [...] of magnetic resonance where we have an external magnet (pointing to the slide) that's it's going to produce a magnetic field. In addition, this magnetic field will guide the nuclei of hydrogen [...] we know that in the component of our body has hydrogen sufficiently, of water [...] And it will be moving exactly with these water molecules. It's going to align the spin of hydrogen [...] We will observe that a fraction of these nuclei are lines up itself, and the alternated field, that is the resonance frequency and you are going to oscillate this field, this change of orientation of spins will be followed of a certain dispersion of energy, for these nuclei of hydrogen, of water molecules [...] Finally, they will start to vibrate. As they will acquire energy in a determined point, they will have to set free that energy, they tend to be "very nice", "calm", thus, without much excitement [...] So, this energy was absorbed and will be thrown away, that is, it’s going to emit this one [...] on the same frequency that it absorbed [...] it’s going to be in the original state, that was calm. And you have some detectors which they’ll pick up these frequencies and the position of these frequencies, from where that energy came from and the body emitted and through this it will get to draw a map [...] This is going to pick up from what position, what place, inside the body, was emitted that determined energy and will map this through the software interface.

Despite the explanation above, about the equipment of magnetic resonance device, seems confused, we perceive, as highlight Hofstein, Aikenhead and Riquarts (1988), that the student teacher tried to articulate the taught science (electromagnetism) with the technology (magnetic resonance device) and the social context, trying to make the students to notice these relations. When he states "it's going to acquire a magnetic property, with all those properties that we already studied, that in the beginning, I believe, that is already well known" the student teacher wants to emphasize that what will be said had already been explained.

Moreover, the use of the expression “extremely quantum” denotes a certain intonation in a degree of difficulty to understand the working of this technological application, and that “it is closely connected to the spin” implies to say that if the student did not understand what the meaning of spin is, he will not understand how the resonance equipment functions.
Conclusions and Implications

Explanations using analogies as didactic resources in the classroom can help the scientific knowledge understanding in order to make also understood its technological applications; however, we have to care in employing analogies in classrooms. The way it were used in these excerpts showed before, for example, firstly saying that there is not a classical analogous, and then inserting analogies to try to explain what spin is, turned the students’ understanding more difficult. According to Stavy (1991), to the learning process be clearly efficient, it is necessary that the use of analogies result from an appropriate familiar situation choice.

Therefore, we emphasize the importance of analyzing carefully these lessons in which, in our case, the student teachers, prospective High School Physics teachers, use analogical reasoning with the purpose to generate alternative explanations for concepts considered abstract.

We also realize that, in this case, these prospective teachers tried hardly to do a connection to the scientific knowledge and its technological applications when they set the proposal to work contents related to the electromagnetism, specifically with the magnetic resonance work. Turning into problem subjects of such a nature in Physics classrooms can open ways to understand the presence of this intrinsic science in our lives, which means, the practical importance of the physics knowledge.

Even though the use of a STS approach in the science curriculum faces many difficulties, we consider the proposal of the course "The other side of Physics" and the prospective High School Physics practice interesting and motivating. Moreover, we know the efforts done to adapt the new curricular proposals to form future teachers in order to follow the new scientific education requirements, particularly in the context of Science in an approaching STS.

In addition, we recognize that it is from investigations like this we report here that we can help to change the reality, as claimed by Cobern, Gibson and Underwood (1995), which recognize that students have not been taught to make connections between the systematized knowledge acquired in school with their daily experiences.

References


THE CHALLENGES OF USING ICT TO CROSS BOUNDARIES IN THE TEACHING OF CHEMICAL EQUILIBRIUM – PORTUGUESE PARTICIPATION IN CROSSESNET PROJECT

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Abstract

ICT are known as providing good results when dealing with difficult concepts. Nevertheless, it is also commonly referred that the use of computers in Education can only be effective when accompanied by a clear strategy, carefully oriented by the teacher. In EquilibrAction, the Portuguese project in CROSSNET, approaches for the teaching of Chemical Equilibrium, based on the use of computational resources, were developed. These approaches were constructed considering difficulties and misconceptions reported and also envisaging the cross of barriers commonly identified in the teaching of this thematic. During the works some materials were constructed by collaborating teachers and uploaded on the project’s Website, which was used later for applying the approaches with the students. Three case studies were conducted in order to conclude about the approaches potential to move from: formal to facilitated abstraction, passive to active learning and learning the concepts to learning in context. Recommendations, suggestions for the upgrade of resources, a group of open questions and reflections about teachers’ practices are some of the outcomes. In the future, we expect to disseminate the project in Chemistry teacher community through the Website, which is the main resource/product of the project.

Introduction

The European Project CROSSNET is coordinated by the IPN from Kiel University in Germany and focuses at “crossing boundaries” in Science Education. "Crossing boundaries“ means to travel along new paths in teaching that allow overcoming common barriers such as science subjects, schools and their sub-divisions or institutions for teacher education (IPN, 2006).

EquilibrAction was arranged as the Portuguese contribution for CROSSNET. This project deals with the use of computational resources potential to cross boundaries in the teaching of Chemical Equilibrium. Although some work related to the use of computers and difficulties in the teaching of Chemical Equilibrium had been done previously (Paiva et al., 2008), a new project has been designed to fit the main objective of crossing boundaries (Fonseca & Paiva, 2006).

Several publications reveal the importance of using ICT (Information and Communication Technologies) in the teaching of Chemical Equilibrium (Russell et al., 1997; Hameed et al., 1993; Sandberg & Bellamy, 2003; Paiva et al., 2002), and a considerable amount of computational resources are available online for the teaching of this thematic. Contrasting with this variety of materials, we continue to watch to the reporting of difficulties and misconceptions (Hameed et al., 1993; Tyson et al., 1999; Huddle et al., 2000; Solaz & Quilez 2001).

According to this scenario we have concluded that developing approaches for teachers to acquire competences concerning the use of computers’ potential appears to be relevant.
Rationale

In accordance to the definition of boundary crossing in the field of CROSSNET, the Portuguese partners relate this concept to the use of educational approaches that allow overcoming common barriers existent in the teaching/learning of Science.

Our national project focuses in obstacles found in the teaching of Chemical Equilibrium and the contribution of overcoming them to an effective learning of this thematic. The barriers to work on and the transpositions intended were selected conjugating references about difficulties and misconceptions (above referred), methods/theories valued nowadays and relevant research results about ICT.

On the literature we can find references to the importance of Constructivism and STS (Science, Technology and Society) perspective in the teaching of Chemistry subjects (Mintzes et al., 1998), and since Chemical Equilibrium is an issue related to both biological and geological systems, it propitiates articulation of knowledge from different areas. An active and in context learning can be facilitated by the use of computational resources since these congregate several media and communication capabilities and allow students to construct their own products to explain models (Mintzes et al., 1998).

Chemical Equilibrium is frequently labeled as a formal concept, difficult to understand, leading to the development of erroneous conceptions (Hameed et al., 1993; Tyson et al., 1999; Huddle et al., 2000; Solaz & Quilez 2001). Computers can help in the visualization of most abstract models and the construction of simulations is frequently recommended (Russell et al., 1997l; Huddle et al., 2000; Mintzes et al., 1998).

Accordingly to the above referred, we focused in following barriers / transposition pairs: passive learning / active learning; learning the concepts / learning in context and formal abstraction / facilitated abstraction. The approach we intend to use in order to transpose these barriers is based on the application of computational resources.

Methods

Accordingly with the main goal of designing effective approaches for the teaching of Chemical Equilibrium based on use of computational resources, a central key question was formulated: “under which conditions are computational resources useful to cross boundaries between teacher education / orientation and teacher classroom practice concerning the teaching of Chemical Equilibrium?” Considering each one of the barriers to work on, three other sub-questions are subjacent to the main one:

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<td>… a passive learning to an active learning of Chemical Equilibrium?</td>
<td>… the learning of concepts to the learning of Chemical Equilibrium in context?</td>
<td>… formal abstraction to facilitated abstraction when learning Chemical Equilibrium?</td>
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Founded on these central questions three case studies were conducted by collaborating teachers in order to conclude about the potential of different computational approaches for the transposition of the barriers. So, in a first phase the project involved the organization and selection of materials, such as simulations, with potential recognized in the teaching of Chemical Equilibrium. Then, with the collaboration of the teachers, we have created support materials (exploration guides, information about difficulties/misconceptions, consolidation materials…) and new resources (WebQuest) in order to complete the approaches designed for the cross of the identified barriers.
The approaches were applied by the teachers with students from three different classes and schools and are available in the EquilibrAction Website: [http://nautilus.fis.uc.pt/cec/ea/](http://nautilus.fis.uc.pt/cec/ea/). Users can also contribute to the Website and exchange documents. This platform is simultaneously the main resource and product of the project.

Different instruments for data acquirement were used, accordingly with the case in study, but triangulation from documentation, observations and interviews/questionnaires was done for the three cases studies. A resume is presented in Figure 1.

**Figure 1. Instruments for data acquirement**

![Diagram of data acquirement instruments](image)

**Results**

From the analysis of the data acquired, that involved quantitative and qualitative methods, the following results stand out:

- From the pre-test to the post-test (approach applied in-between) the students revealed to have improved knowledge, although not for all the misconceptions involved;

- Students got focused in the tasks for longer periods and several indicators were found for the participation in activities that potentiate cognitive involvement. Nevertheless, no indicators were found for the self regulation dimension;

- The work done by the students obeyed to the large majority of evaluation parameters defined for the learning in context approach;

- Some transversal difficulties were detected such as dispersion of the students, lack of optimized computers/internet access and time constraints;

- Some open questions still remain, like groups having similar answers due to the discussion between elements or cheating?;

- Teachers’ reflexion pointed that improvement is needed in the materials used.
Conclusions and Implications

The results point out positive outcomes from the use of these approaches, since improvements were registered in knowledge, motivation/participation of the students and capability to learn in context. So, further development and dissemination of the approaches, through the Website, is predicted. Nevertheless, it is important to recall that several difficulties were found and in some cases not solved, showing that the approaches are not a miracle solution, but just a contribution to help transpose this barriers.

A last word goes to the importance of the teachers’ role in this process. Reflections made by the teachers about their practice led to a list of recommendations useful for the upgrade of the resources. This reflections also pointed out the importance of the carefully preparation work from the teachers’ part in order to minimize technical problems and time constraints.

References


ELECTRICAL FIELD LINES IN THE MEANING MAKING:
A MULTIMODAL STUDY ABOUT THE ACTION IN THE CLASSROOM.

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Abstract

In this paper, we present a qualitative study based on the analysis of physics explanations in the classroom of three lecturers on Physics. The experience is carried out in Venezuela, in the School of Engineering at the University of Carabobo. The purpose is to analyze how the lecturer on Physics uses the field lines like support in their electrical field explanation, identifying the multimodal resources and its function in the process of scientific meaning making. The final data is presented seeking to be useful for any science teacher. Throw of a transcription process, the table contains the lecturer speaks, drew of the slate, lecturer movements, and photograph shots. The analysis from the perspective multimodal takes into account the role of visual representation through action. The results lead us to reflect on the field lines role in the meaning construction process of the lecturer, not only for the electrical concept field, but for the development of three-dimensional vision beyond the paper, basic competence in the engineering student. This work is an advance of a bigger study, motivated by to know a specific context of physic teaching for to design program toward improve the lecturer's capacities. Keywords: multimodality, rhetoric, teaching physics, electric field lines.

Introduction

Since some years, in the electromagnetism program of low studies in the Engineering Faculty at University of Carabobo, in Venezuela, the usefulness of field lines concept for the development of meanings in electrical field has been under discussion. Results of researches on the Engineering students' difficulties about some Electromagnetism concepts highlights that the teacher needs to undertakes a process of knowledge’s construction in the classes in which students familiarize and assume the model of field lines and of the other notions and concepts related to field lines model, as the flow and field circulation notions. We investigate on this issue from a multimodal perspective.

Gros (2004) points out that a new lecturers initially is recognized himself as physical or engineer professional more than as lecturer. The new lecturer focuses initially more on the subject matter to teach, being more worried about the subject matter than about the way of organizing the specific content and of designing educational activities for students to learn, or the teaching techniques, and from them, there is difficult to control time, space, interaction with students and management of groups’ work. Over time, it is observed in the new lecturer a gradual separation of the text book, the script in the blackboard, and begin to concern about whether students are learning or not and how to improve the dynamics of classes. Eventually, the lecturers going to leaving aside the concern on
themselves and start trying to understand the effects of their actions on the meaning making process in their students.

We present a qualitative study consisting on the analysis of three Physics professors’ explanations teaching a Electrostatic topic. It is intended to describe the use that professors make of field lines for the construction of meanings. The analysis will be done from the multimodal perspective and specially taking into account the role of visual representation through action.

The aims of this study are: a) to analyze how the Physics lecturer uses the ‘electrical field line’ in the construction of electrical field topic, b) to identify the resources used for the professors to give multimodal presence to the field lines and which function the multimodal resources make; finally, from results obtained with the analysis done c) to reflect on the field lines role in the scientific meaning construction in engineering student.

Discourse analysis: the Perelman’s argumentation theory.

Aristotle defined the rhetoric as the art of speaking in a convincing way from reasoning. But, the ancient art of persuasion with the time was reduced to an ornamentation theory or elocution, in the common perception in everyday language. Perelman and Olbrecht-Tyteca (1958), with the book “Traité de l'argumentation”, returns to the conception of rhetoric as a persuasive discourse theory with the argument in its axis. It is the great renaissance of rhetoric as a discipline, like a science discourse, where the language and its functions are examined, trying to discover which arguments could persuade audience.

Our approach to the explanations of teachers starting from the theory of argumentation of Perelman Olbrecht-Tyteca (1958/2000) aims to study the discursive techniques that allows to increase the adhesion of the public’s minds to the thesis (new ideas, concepts, laws or scientific theories) that are presented for their acceptance. It highlights elements to characterize the discourse: a) the premises (agreements accepted by the audience and will be the starting points of argumentation), the importance of presence to be given to the premises to increase their rhetorical or convincing value; b) how to present the discourse (prosody, verbal forms, the rhetorical devices used) and the strategies for achieving the communion with the audience; c) argumentative schemes and techniques d) the interaction of the arguments

Like Aristotle, Perelman and Olbrecht-Tyteca (1958) considers that a discourse to be effective has to focus on the knowledge of the audience, to whom it directs the persuasion techniques, and considers necessary to find the most appropriate ways to create participation – that could be only mental- of the audience in the discourse (communion), so, an adequate discourse to specific audience requires human empathy, ability to take point of view of others, taking the pulse of the situations, learning from silences. This theory (Perelman and Olbrecht-Tyteca (1958) combines a rhetorical approach with an argumentative one, and which has proved to be a good framework for analysis of a Physics lecturer discourse (Fagúndez, 2006; Castells et al, 2006).

In terms of rhetoric, the lecturer’s explanation has to convince students of their thesis (scientific points of view) and this is accomplished first by preparing the audience for the discourse, then with the discourse adaptation and choosing a form of presenting the discourse, which all them contribute to maintain the pursuit and the attention of the student during the discourse. On the bases of this theory we have initiated (Rangel, 2005) this research for to

3 Meaning making is a term used to call the process of construction of Knowledge (ideas, notions, concepts, relations between them, specific skills, etc…), into a social constructivism perspective (Scott and Mortimer, 2006)

4 Presence is a concept from the rhetorical-argumentative perspective (Perelman,1982) that means the arguing always includes procedures by which ideas and values can be given special presence (in French sense of being made present) in the minds of those addressed.
study the lecturer’s action in the classroom for the scientific meanings’ construction into the multimodal perspective.

Physics professor’s discourse and their action in the classroom.

To think about improving education in our context, we must be aware of what means for us, as lecturers, the teaching process. In the Physics teaching, scientific concepts are presented in different ways, using graphs, equations, with everyday examples, with body representations, and with various actions in the classroom. Seen from outside, the scientific concept can be defined with only few lines of a paragraph in a text, but there is a very big distance between that idea, and the students understanding of the concept, that means they will be able to apply the concept in problems’ solving or answering proposed questions in the classroom or in the evaluations.

A verbal text does not build the same meaning as a drawing, or the mathematical graph the same as a mathematical equation, or a verbal description as the same performing an action (Lemke, 2002). Lecturer combine verbal language with elements of graphic language and with mathematical language and formal elements, and with body language, acting on the physical world, carrying out actions with material objects, with the aim of developing a coherent discourse that encourages students to "see" and "interpret" the physical world according to the scientific meanings that are being developed in class and in this way are making the meanings. (Ogborn et al, 1996).

In his research, Kress, Jewitt, Ogborn and Tsatsarelis (2001) show us the rhetorical functions of objects that mediate the action in the classroom, to give "presence" at the built entity, thanks to which students can see new features and qualities when they are building the concept. Among them, there are a) shows the imaginary, where an identity is present to the student through the action with the body, the body which acts as a rhetoric sign, and b) the demonstration using physical objects.

The use of field lines model in the Physics’ program.

Several Physics lecturers and a professor have been interviewed about their position about the use or not of the field lines concept into the program of Physics in Electrostatic. Between them, we find three positions: first, “The field lines are very necessary to construct the concept of electrical field because they facilitate to the student be possible to describe the intensity of field and to orient to the electrical field vector that is not a visible concept...”, the second and intermediate position: “I explain the field lines, it is a compromise within our program but I’m not convinced of the usefulness of this concept because it could to create wrong ideas in the student, and the third position: “I think that it is not necessary to explain the electrical field lines model for teaching and evaluating the electrical field ..”.

Rationale

The relevance of this study is its contribution in the lecturer training, like a piece of a bigger whole. Our global objective is to design strategies to improve the Physics lecturers’ action in the meaning construction apart of developing their critical and reflexive capacities in relation to the Physics contents. A way to do so is to investigate about Physics topics that concerns themselves and at the same time, to work in a inquiry process to know and to describe the teaching context in the classroom. In this case, the concern is: how helpful is to the student the electrical field lines in the construction of meanings of Electromagnetism. Furthermore, we want to work to create in the lecturer in formation, the reflection about different communicative modes and its function in the construction of meanings.
Therefore, this investigation intend to do a reflection about an interesting question in the context of the Physics teaching based on the lecturer’s praxis, and to identify the function of the several multimodal resources in the teaching.

**Methods**

This work is an advance of a bigger study that tries to describe the Physics’ teaching process through of discourse analysis in the classroom, in order to contribute to designing a program of formation to improve the lecturer’s teaching capacities. There is a qualitative research, based on case studies; it is an analytic and descriptive study, aiming to capture processes happening during the teaching.

**Context:** The experience is carried out in Venezuela, in the Engineering Faculty of the Carabobo University, taking like reference the discourse of three professors and lecturers experienced in teaching Physics: Laura, Montse and Pere; all of them with different opinions or position related to the useful of field lines within the Electromagnetism program.

**Data** was gathered through direct, non participative, observation, supported by the video recording of classes and researcher’s field notes. The information was divided in episodes according to the themes, and separated in segments of one minute each one. The final data is presented seeking to be useful or any science teacher. Through a transcription process, the table contains the lecturer speaks, drawing on the blackboard, lecturer's movements, and photography shots.

The **sample**, we select from the data collected a selection taking account those segments of discourse where the premise ‘electrical field lines’ appears to construct an aspect related to electrical field concept. The analysis was made from the multimodal perspective that takes into account the role of visual representation through action, from which the segments were analyzed, based on the issues identified from the analytical framework.

The group class is integrated by 60 engineering students, third course, 18-20 years old. It is necessary draw that in this classroom of theory, it is non common the use of resources like experimental demonstrations, video beam, projectors and other electronically resources. The professor disposes only of a blackboard, eraser, and markers.

Analysis of the professor explanations

Following is the synthesis of the analysis carried out in certain segments of the professors’ discourse, in the construction of electrical field topic, supported by the ‘electrical field line’ concept. We will comment about four examples, where we identified the resources used for to give multimodal presence to the field lines.

**Example-1: How many lines pass through of this surface?**  “looking the intensity of electrical field”

Laura, in the construction of electrical field concept, introduces the electrical field line, in a way very detailed. In the figure 1, we show part of her discourse in the segments: (Laura; B06-B11).

She uses a system of representation using physical objects. She starts taking a bag pen like a surface unit, emphasizing it with their global expression: her voice, her gaze, and the inclination of your body. In the segments B08,B11, she represents an electrical field non uniform drawing curved arrows on the blackboard. She works the notion of system using the bag pen and the figure on the slate to give presence to the surface unit, while attracts the attention of students about the intensity of the electrical field in two different zones of the systems. Laura: ¿How many lines pass through of this surface?
The magnitude of electrical field is proportional to what we call the density of lines of force, or electric field lines (she write it on the slate)... its define the density of lines as the number of electric field lines ... (writing) per transversal surface unit.. (and she emphasizes) -Laura: .. What does this means?

Laura: (looking to the students) What does this mean? .. we let's take a surface unit ..it could be, for instance, this bag pen .. (get up and shows the bag pen) is it right? and I'm going to move the bag pen in a region of space immersed in a electric field, where the field lines are perpendicular to whom? .... to this surface .. So it is said transversal surface unit. (she shows the bag pen and repeats) (..) I take my surface unit and I will move (she extends her arm to move the bag pen) my surface unit across the room to see how it changes, which thing is changing?... "the electrical field", and I will have (she inclines her body and turns left, then right, looking the audience,) provided that surface unit perpendicular to whom? to the field line, okay?

Then we let's see an example here. (..). (she draws lines without speaking) okay? (she turns and she looks at the students) .. Let these lines of force, (she points to the lines drawn on the blackboard) okay? Let these lines representing the electrical field in any region of space. Then, I take my surface unit and we determine the number of lines across my surface unit here. (put the bag pen on the figure drawn in the slate and she moves the index finger along the figure up / down) How many line do pass across? (students: three) .. three..., and in this region? (she put the bag pen in the bottom of the figure) .. (pause) (students: one). (…)

Then if I take my surface unit, and I put it perpendicular to the electric field lines (points supporting hand on the figure) in this region of space (put the bag pen on the figure draw in the slate and move de index finger along of figure up / down) .. how many lines pass through of this surface? (students: -"four!") ..four .. if now I put the surface here (she put the bag pen in another part of the figure) .. and how many lines are going to pass through this unit area? (students: - one!) One..

Figure 1. Laura discourse example: Making visible the electrical field intensity.

**Example-2 : Which Gaussian surface do we go to choice? - “looking at the electrical field”**

Montse, in the construction of electrical flow concept, illustrates a known systems of electrical charge used previously in Coulomb law classes (punctual charge, infinite rod, and the infinite plane) to determine the electric field. She aims to explain the usefulness of Gauss's law to determine the magnitude of electrical field in a charged plane, to strengthen the equation, and to recognize how to select Gaussian surface through which the integral will be evaluate.

In the figure 2, we shows the first segments (Montse; E23-E27) of the explanation, of Montse, we note that while Montse speaks, she always uses her body join other non verbal resources such as: a system sketched in different views on the slate, a sheet of paper as the background to explain the view drawn on the slate, a sheet of paper changed into a cylinder, a notebook of a student to simulate the plane.
Montse: - Let's put this plane (she touches the figure) in other view from side. (..) we will see from this side view. (Montse uses a sheet of paper like a plane, and she places it on the figure. And then she put the sheet of paper perpendicularly to the slate).

Montse: Which would be an appropriated surface to calculate the electric field? .. Because we know from symmetry .. that the electrical field of a positive charged plane .. must be (..) (Montse uses her arms and fingers like field lines. She places hands on the board with the fingers spread and extended out horizontally)

Montse: - So, Which would be the gaussian surface to choice? (student: -Cylinder!).(..). let me see .. (Montse takes a paper and turn into a cylinder...and she put vertically on the figure while make her explanation). Montse: - now we have a cylinder ... (..) and if we place the cylinder in this way and we evaluate..? (students: -No!.. no? Why?..(students comments) (..) (Montse takes a notebook like a plane) Well, we suppose that this notebook is the infinite plane, okay? and ..(.)

Montse continues her explanation differencing the field lines and the surface vector in any point of cylindrical surface area, and next, she changes the position of cylinder, she put the cylindrical paper perpendicular at the slate on the figure, she explains, and finally she put the cylinder in horizontal position.

Figure 2. Selection of a Gaussian surface: finding relations between electrical field and surface vector

**Example-3: I am the punctual charge and my arms are field lines – Mimic Representation**

Pere, in the construction of electrical flow concept, illustrates a punctual electrical charge used previously in Coulomb law classes to determine the electrical field expression. He aims to demonstrate that the result is similar to that of coulomb law, and she tries students recognize the importance of a good Gaussian surface selection to facilitate the integral solved. To achieve it, Pere, in his discourse, needs that the students can “see” both, the punctual charge with its electrical field, and the Gaussian surface with its surface vectors, analyzing the symmetry between them.

In the figure 3 we shows the segments (Pere; E1-E4) Pere drawn on the slate the charge in the center of a yellow sphere representing the surface gaussian selected. He draws field lines and small rectangles above the sphere for indicate a differential surface with its surface vector respectively. For “to see” the electrical field, he draws lines that represent the field lines but the slate is not enough, and Pere in the segment E4, E5 use the mimic representation for to give visible characteristics in tridimensional space of electrical field, using the field lines.
Pere: -But these are lines that are on this plane, okay? (he is going with her hands to center of the field drawn on the board, and sweeps his arms out, back to students, and looking at her with the students) .. but there are lines from charge coming out slate also, and are pointing to out, in, right, left, everywhere.. Okay? ..

(While Pere speaks, he is in the center of the sphere. Pere stayed in front of the drawing in the slate, he uses the mimic representation of field lines to give presence to electrical field. In the construction he simulates radial lines with arms and fingers like arrows. In this moment, he represents the charge).

Pere: -But any of these electric field lines (with his arms open crossed) at any point on the Gaussian surface are parallel to surface vector .. right? .. yes or not? .. true or false? (Students comments) - Can you imagine it? (He make a pause with his open arms waiting for feedback)

Figure 3. Pere discourse example: Making visible the electrical field of a punctual charge.

Example-4: If this classroom walls form a cube and we put a point Charge in its center – Imaginary System Representation

After of Pere explaining the electrical field of a punctual charge using a spherical surface, he built in this discourse (Pere; E8-E9) the same system but with other Gaussian surface. In the figure 4 we show how Pere recreates a imaginary system inside the classroom. He aims to create the environment to think about the correct selection of the Gaussian Surface, analyzing the symmetry with the field lines trough the visualization of the relations between both vectors: surface vector and electrical field in different surface points.

Pere starts a dynamic phase by questioning the students about how is the surface vector at different points on the walls compared with the electrical field vector using as support the field lines, until finally to arrive that a cubic surface is not a good choice. Pere is verifying the students understanding and he promotes the communion of audience.
Pere creates the environment to think about if a choice of a gaussian surface is adequate, creating differences between surface vector and electrical field.

Pere: “..if I choice a cube?..”(..) I will have a problem.. because I can't solve an equation like this.. (..) We go to imagine that classroom walls form the cube and the charge is here, in the center. (pointing).. (..) How are the area vector respect to the electrical field lines?.. come! .. ¿can you imagine? ..”

(his arms represent field lines in different imaginary points and he ask to students to compare it with area vector until verifying with the students that cube is not a good choice).

Pere: ¿How are the area vector respect the electrical field lines?.. come! .. ¿can you imagine? ..”

Figure 4. Imaginary representation: the walls are cubic surface and centered is the punctual charge.

Results

Although teachers had different ideas about usefulness of to use lines field model; all of them used it. The electrical field lines play a main role in the meaning construction process of electrical field thesis.

Among the results, there were different types of representation of the premise and varied functions. Among the types of representation was the use of: a) spatial representation, through visions, b) the use of the body and arms to give presence to the directionality of the electric field, c) the spatial representation, using objects physics, d) the representation on the board, with colorful drawings.

Some of the features that meet the electric field lines, found in the explanations of teachers are: a) to differentiate and analyze the behavior of the vector differential area of the electric field at different points, b) to think about the proper selection of Gaussian surface, to direct to the area of Gauss's law, c) creating regions with electric field, discussing the quality of relationships and identifying major / minor -intensity of electric field.

Multimodal representation of electrical field lines. Premises and ways to represent.

We analyzed the explanations of professors and there were different kinds of representation of the electrical field lines. Among the types of representation used we have found: a) using the body and hands to give presence to the directionality of the electric field, b) drawing the figure in the slate, for the representation of a system, drawing colorful figures, c) using many times the same object on the slate, drawing several figures from different views. So, he achieves to give to the object tridimensional attributes, d) using the spatial representation, through of mimic, c) using the imaginary representation involving all the classroom, or using improvised objects.
Functions of Multimodal representation.

In the building of electrical field concept, we distinguish many types of function. The first, specifically related to the Physics concept and other related with the development of abilities necessaries in the engineering. The professors use the electric field lines model for: a) To give a system to differentiate and to analyze the behavior of surface vector from the vector electric field at different points, creating differences between surface vector and electrical field, b) to reflect about the most appropriated selection of a gaussian surface, to apply Gauss's law, c) to create regions with electric fields, to observe several points and qualitative relationships of the electric field evaluated at each point, major-minor electric field strength.

Also are observed other functions of multimodal representation, mainly in imaginary system representation. During the explanations in the teacher highlight, the need to recreate the tridimensional view (3D) using the electric field lines, to develop a basic skill in students of engineering (the 3D mental picture) applied initially in a basic skill: the understanding of the vector surface or electric field. Other function in the use of the imaginary representations is the high level of presence achieved. In this way, many multimodal resources are interacting between them and the students are immersed into them forming part of the imaginary system. This dynamic of teaching gives strength to the communion to facilitate the learning.

Conclusions and Implications

Electrical field lines play a main role in the meaning construction process in the learning about the electrical field phenomena. We studied the explanations of three physic professor, with different ideas and positions regarding the utility and use of field lines model within electromagnetism program, and even then, we noted that all three professor used the field lines. The multimodality is present in the example, the verification, and so. It makes possible the student persuasion for his participation and attention in the explanation (communion).

On the other hand, there is the effort of lecturers in the meaning construction during the explanation through different modes of communication, emphasizing the spatial aspect visions through the use of the body and arms to the electric field vector presence, spatial representation, using physical objects, the representation on the slate, with colorful drawings, among others.

In the engineer work, in any expertise area, is common the design and implementation of systems not even built. To do this you must create and recreate systems are initially so imaginary. In the science teaching process imaginary systems are often recreate, also the three-dimensional view (3D) is highlighted using the electrical field lines in the explanation. This is a basic competence to develop in the engineering, and we notes that the professor makes use of all available resources to create in the classroom to create three-dimensional images of systems, contributing thus to the competence of the future engineer. The professor uses the mimic and imaginary systems representation to give visible presence to some concepts and to construct non visible concepts.

In summary, the results lead us to reflect on the role of field lines not only to the concept of electric field, but for the development of the three-dimensional vision beyond the specific role for the construction of electrical field meaning. Besides having clues about how the different modes of communication involved in the explanations contribute to the creation of scientific meanings. Results of this investigation open us new ways for lecturers’ training in order to improve the physics lecturer’s praxis, relative to their communicative capabilities for to build a discourse that could be effective for a specific audience.

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References


INQUIRY SCIENCE INSTRUCTION OR DIRECT?
EXPERIMENT-BASED ANSWERS AS TO WHAT PRACTICES
BEST PROMOTE CONCEPTUAL DEVELOPMENT
OF SIGNIFICANT SCIENCE CONTENT

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Abstract

This paper reports on an experimental investigation of the efficacy of science inquiry instruction vis-à-vis direct instruction for middle school science. Science education standards reflect a commitment to the teaching of science as inquiry across the K-12 grades, i.e. instruction reflecting the investigative approach scientists use to discover and construct new knowledge. Nevertheless, there remains educational and political debate about instructional approaches, across a spectrum from didactic direct instruction through degrees of guided inquiry to open discovery learning. The science education community has overwhelmingly adopted a guided-inquiry perspective. Since the science curriculum projects of the 1960s, teachers, researchers, curriculum developers and policymakers have had an interest in knowing the effectiveness of inquiry-based curricula and instruction. Proponents of inquiry point to studies which support it, but critics counter that little of this research is comparative, controlled or unconfounded. In various states there is political pressure for a return to direct instruction in both science and math. The lack of convincing research evidence in favor of inquiry is thus of concern, and hence our group has designed and undertaken an experimental study to test the question: is inquiry instruction superior to direct, for science conceptual development? This paper addresses this question.

Introduction

This research studied the efficacy of carefully designed inquiry instruction in science against equally carefully designed direct instruction, at the middle school grade level. Inquiry teaching of science refers to teaching that reflects the investigative attitudes and empirical techniques that scientists use to discover and construct new knowledge. A related idea is that of “Scientific Teaching” (Handelsman et al., 2004), wherein “the teaching of science should be faithful to the true nature of science by capturing the process of discovery in the classroom.” Many educators feel that inquiry teaching is most in keeping with the widely accepted constructivist theory of how
people learn; but constructivism is a theory of learning, not of instruction. Students must construct their own understanding regardless of resources, whether laboratory activities, lectures, discussion, or text.

The origins of the modern day concept of science teaching as inquiry lie with the 1960s NSF-funded curriculum projects. In recent years, under American Association for the Advancement of Science (1990), National Research Council (2000), and National Science Foundation leadership, the United States has developed a national commitment to the teaching of science as inquiry across the K-12 grades, and almost all state frameworks for K-12 science education have an inquiry focus. The science education research community has overwhelmingly adopted an inquiry pedagogy perspective for science education.

With the advent of these curriculum projects and standards documents, various stakeholders such as teachers, researchers, curriculum developers, and policymakers have been interested in the effectiveness of inquiry-based curricula and teaching with respect to science concept achievement. A wide variety of research and evaluation projects have been carried out, and proponents of inquiry teaching claim that this body of work generally supports the effectiveness of inquiry instruction. Their stance is not unanimous, however, and critics are quick to point out that the research support for inquiry instruction may be weaker than it seems at first glance. David Klahr (2009) suggests that little of the research is comparative, controlled or unconfounded. Likewise, a recent meta-analysis conducted by the Educational Development Center (2009) of research studies into inquiry instruction does not find them to yield sufficiently unconfounded inferences to adequately address the central issue. In fact, the EDC reports that research rigor declined from 1984 to 2002.

In various states there is political pressure for a return to direct instruction in both science and math. Kirschner, Sweller and Clark (2006) published a paper entitled “Why minimal guidance during instruction does not work,” and Sweller (2009) has offered a critique of constructivism. Given the widespread advocacy and the adoption of inquiry science instruction by many educators, and of direct instruction by other stakeholders, the lack of unconfounded experimental research data in support of inquiry is cause for concern.

Though convincing comparative evidence for the superiority of either direct or inquiry science instruction is hard to come by, it is evident that “experientially-based” instruction and “active student engagement” are advantageous for effective science learning. However, these “hands-on” and “minds-on” (Alberts, 2009) aspects can occur in both inquiry and direct science instruction. Thus, the pertinent question is not whether active, experiential learning of science is more effective than passive, non-experiential learning. The question is whether an inquiry approach or a direct approach to experientially-based, engaging instruction is more effective for science concept development, when both approaches are expertly designed and well executed.

Rationale

Our group has designed and undertaken a controlled, experimental, comparative study to investigate the question: “Is inquiry instruction superior to direct for science conceptual development?” Our research compares experientially-based Inquiry Instruction and experientially-based Direct Instruction for science conceptual development in realistic science classroom situations at the 8th grade level. We sought to avoid particular threats to research validity, including use of a poor or unspecified alternative to inquiry, the lack of randomized assignment of subjects to groups or controls for differences, the lack of independent, relatively objective evaluations of implementation and fidelity to method, and the lack of treatment specificity that might enable replication. Our research was designed to have the following features: Specificity, Fidelity, Objectivity, and Transparency.

Research Features:

The research was initiated in response to the National Science Foundation’s Interagency Education Research Initiative (IERI/NSF 04-553) call for employing research and measurement designs that are demonstrably valid and reliable with a premium on experimental designs with random assignment of subjects. We think that quantitative
research encourages precision of research and that its findings can provide an important threshold, a floor, a common ground from which to pursue further research, including qualitative research, without becoming reductionistic. One does not need to give in to the extremes of reductionism to value the notion of “active agent”—so for example, what makes inquiry pedagogy “inquiry”? We know that there is a range of instructional activities that we call inquiry; what is it they all have in common that makes them “inquiry”?

For our purposes, we specify explicit models depicting unit structure, components, sequencing and approach, making clear what is different and what is common between our “inquiry” and “direct” modes. Our “Guided Inquiry” instruction model is based on the Karplus Learning Cycle (Lawson et al., 1989), with Exploration, Concept Formation, and Application. Students are guided toward “inventing” relevant scientific concepts and “discovering” the relationships and laws, guided by the instructor. In contrast, Concept Presentation & Explanation, Illustration & Confirmation, and Application, are the phases of our direct instruction model, with the teacher presenting and explaining concepts, relationships and laws directly to the students, as finished products to be learned and understood. We call our direct model “Direct Active” since it includes hands-on practical work, though of a confirmatory nature and with prescribed steps. Both models are intended to represent good practice toward meeting middle school science objectives as described in national and state curriculum frameworks, and both models involve the instructional components of science/mathematics integration and experiential science learning that are supported in the literature.

Fidelity to mode and to curriculum are also important features of the research. Teachers practiced in advance, and were evaluated for fidelity during teaching in three ways. First, independent specialist observers from the Science and Mathematics Program Improvement group (SAMPI, 2009), initially “blind” to teacher mode, visited two lessons per unit for each teacher, two observers seeing each teacher and scoring them on fidelity to method. They successfully identified modes for each teacher, and were subsequently able to score teachers specifically on fidelity to the intended lessons. The second fidelity check was that teachers kept journal notes on each day’s teaching, and third, lessons were videotaped for review.

Our research design had several areas of blindness to enhance objectivity and minimize bias; teachers were blind to the independently developed assessments, SAMPI was initially blind to teacher mode, and SAMPI coded and analyzed the data without knowledge of group. In the interest of transparency, we have placed all critical study information on our project web site (Way2Go), including complete unit descriptions, learning objectives, student materials, teacher guides, and assessments.

Research Design:

The research utilized a true experimental design with students randomly assigned to treatment and control groups, both of which are specified in detail and hence are in principle replicable. The design and development of the instructional units for each mode were based on accepted models that have support in the literature. Applications and assessments were identical for both modes. Teacher fidelity to intended method and to lesson implementation was monitored by the independent observers initially blind to teacher assignments.

Two science unit instructional topics of substantial conceptual demand were chosen for the research, appropriate at the 8th grade level, and consistent with national frameworks:
It's Dynamic! The concepts of force, motion and mass, and their interrelationship in Newton's first and second laws of motion.

It's Illuminating! Basic science (light energy depends on angle, distance, time), and application to temperature variation on Earth due to location (latitude) and time of year (seasons)

The inquiry and direct versions of each science unit (hereafter referred to as “Dynamics” and “Light”) were designed in parallel, to ensure equivalence in science content and approximate teaching time, while differing in the sequencing and epistemological bases of experiential activities. As specified above, the essential aspect distinguishing inquiry and direct modes was boiled down to the “active agent” of “how students come to the concept.”

Research Questions:

The major research questions formulated as null hypotheses are that 1) There are no significant achievement gain score differences between direct and inquiry approaches, as specified by our Models, and 2) There are no significant achievement gain score differences between teachers within instructional topics, within or between pedagogical approaches.

Methods

To date, research trials have been held for two weeks each June in both 2007 and 2008. Student/subject participation in the project was voluntary, with 8th grade students responding to advertisement flyers sent to their homes by school district offices. Students were randomly assigned to treatment groups/classes, which were taught by five experienced middle school science teachers. For four days each week, the five classes met in the mornings to cover one lesson from each of these two science units, with an intermission snack break. Students were embedded in classes, and each class had a dedicated teacher embedded in a particular mode of instruction. Three teachers taught by “inquiry” mode, two by “direct” mode (teachers will switch roles for the subsequent two years of trials, so as not to cross-contaminate modes within teachers, while still permitting analysis of natural “teacher effects”).

Being a voluntary summer program, the instruction was in-class only, with no opportunity for homework, and only intrinsic motivation rather than the added goal of achieving high grades. On the first and last days of the program, identical pre- and post-tests were administered for both the Light and Dynamics Units. Both tests contain problem-based, multiple choice questions, several per conceptual objective, at Bloom’s taxonomy levels 2 and 3 (understanding and applying). These assessments yielded basic data of each student’s raw percentage gain scores in each topical unit. Normalized student percentage gain/change scores were also calculated, to guard against potential inflated gain bias that might be due simply to the absence/presence of prior experience in the science topic. Normalized change is the gain or loss over the maximum possible gain or loss respectively, expressed as a percentage, and can help avoid possible distortions due to negative normalized gains (Marx & Cummings, 2007).

Analysis focuses on these percentage gain scores, and how they differ between different categorizations of the experience of the students/subjects. Statistical comparisons were made on both raw and normalized gain scores across various groups (modes of instruction, teachers) (by t-test and ANOVA, α=.05), for both the Dynamics Unit and the Light Unit. The unit of analysis is the student, which allows the later study of interactions to include “personological” factors, race, gender, attitudes, and aptitudes.
Results

Differences in results within teachers between years were not statistically significant, thus could be viewed as replication data with different students and aggregated to study other factors. Therefore, results and data analyses are reported from trials run in the summers of both 2007 and 2008, involving a total of 180 students, 72 taught by Direct mode, 108 by Inquiry mode.

Teacher fidelity-to-mode median rating of 86% is arguably adequate for our research purposes while remaining realistic with respect to inevitable variation in actual science classrooms. Student scores on the pre-tests indicated that randomization of students across classrooms was effective, i.e. any variation in pre-scores between classes was consistent with that expected by chance for these class sizes.

Average pre-test scores on the multiple choice assessment instruments were around 50%, with standard deviations around 20%. We found statistically significant though modest gains in each subcategory we analyzed. Standard deviations on post-tests were similar to those on the pre-tests. Figure 1 shows a representative distribution of pre- and post-test score data, for the case of the Light unit in Inquiry mode.

![Figure 1. Example of Distribution of % Raw Gains, Inquiry Groups, Light Unit, 2007-2008.](image)

The overall (both modes) raw percentage gain in the Light Unit over two years (M=13.6%, SD=15.3), is statistically significant ($t(179)=11.934, p<.001$), with an effect size (Cohen’s d) of .69. The overall raw percentage gain in the Dynamics Unit over two years (M=9.7%, SD=13.5) is also statistically significant ($t(179)=9.655, p<.001$), with an effect size (Cohen’s d) of .54.

Mean normalized percentage gain/change is on the order of 30% for the Light unit and 20% for the Dynamics unit, for both treatments. Effect sizes (Cohen’s d) for normalized gain were 1.40 for Light and 0.99 for Dynamics. Raw gains showed consistent (negative) correlation with pretest scores, but normalized gains did not, indicating that normalization was working in this regard, and that pretest scores were not a good predictor of raw gain.
For a sense of perspective, these gains are on the same order as those from a large survey (Hake, 1998) of courses which used the well-known Force Concept Inventory (FCI) for pre and post testing in mechanics, where typical normalized gains varied from ~ 20% for traditional courses to ~ 35% for courses involving more active engagement. Note that our assessment items, like those on the FCI, are conceptually demanding, involving application of the concepts to cases, not just knowledge recall. Project data shows that students get higher gains on factual knowledge, but our stated objective was conceptual understanding.

Comparative results for the Light Unit and the Dynamics Unit are displayed as bar charts in Figure 2 and Figure 3 respectively, with standard error bars overlaid, and accompanied by tabulated values for scores, gains, and standard deviations. The two charts display results by topic, teacher, and instructional mode, data aggregated over two years. The “central” sections of Figures 2 and 3 represent the results regarding the “central” research question, comparing Direct and Inquiry instruction.

Figure 2. SUMMARY of Light Unit Results for 2007-2008.
Regarding the central research question, for the Light unit over two trials, the difference between direct and inquiry groups on normalized gain/change was not statistically significant ($t(178)=.755, p=.451$) (mean diff. 3.8, std. error diff. 5.1, effect size Cohen’s $d=.12$). Raw gain had a small but statistically significant difference between one Direct teacher (Ann) and one Inquiry teacher (Tom) ($t(73)=2.132, p=.036$); upon normalization the difference was not statistically significant ($t(73)=1.857, p=.067$).

Similarly, for the Dynamics unit over two trials, the difference between direct and inquiry groups on normalized gain/change was not statistically significant ($t(178)=.717, p=.474$) (mean diff. 3.1, std. error diff. 4.4, effect size Cohen’s $d=.11$).

In addition, over two trials, no statistically significant differences in normalized gain/change were found between different teachers within the same instructional mode, even though “natural variations” in personal teaching style and practice were clearly evident from observation. Standard deviations reflected the wide range in scores (and student motivation) in this strictly voluntary program.

Figure 3. SUMMARY of Dynamics Unit Results for 2007-2008.

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Conclusions and Implications

Gain differences between instructional modes were not statistically significant. Given observed natural class and teacher variation in realistic classroom situations, good inquiry and direct instruction led to similar understanding of science concepts and principles in comparable times. Thus advocacy of either method ought not to be based on science content acquisition alone. Given such score spreads, both gains and gain differences would need to be larger than those observed in order to show statistical or practical classroom significance. A single larger-scale study would of course provide larger N size, but at the cost of precision, since it becomes more difficult to prepare, control and monitor instructional and classroom situations, thus increasing variation. Following Cronbach (1975) a number of separate local studies in various environments would be more informative, to see whether and how the findings generalize to other situations and to refine and study the effect of various parameters.

Mastery of science content in the alternative modes was our central research question, but the inquiry-versus-direct debate is not just about content: it is also about the nature of science and about efficiency. Most science educators feel that Inquiry Instruction, by its very nature, provides crucial added value, in having students “do” science for themselves. For Direct Instruction, given our finding that it does not lead to a better grasp of the basics, it is not as clear what other grounds there might be on which to argue superiority. It may be easier or less time consuming for the teacher, or less demanding for weaker students, at least initially. However, direct instruction risks sending the message that science is simply a body of knowledge to be learned.

Given the composite nature of all good lessons, and the realities of implementation in classrooms, we see that common claims for superior concept acquisition by either direct or inquiry instruction may be viewed as overstated. It’s possible that under even more tightly controlled and rehearsed conditions one could better distinguish the performance effects of mode of instruction, which would be of significant theoretical interest; but this study gives a practical indication of what is more likely to happen in the field. Thus, the continued promotion of one mode of instruction over the other, where both are based on sound models of expert instruction, again, should not be based on content acquisition alone.

If we continue to advocate inquiry we need other grounds for doing so, such as appreciation of the nature of scientific inquiry, attitude toward science, transfer of knowledge to new situations and longer-term retention. Each of these, however, is a new research question. Inquiry-based instruction clearly offers significant potential advantages for science education, by modeling scientific inquiry during concept learning; these concomitant benefits would need to be studied in research designed for that purpose. However, as far as science concept understanding is concerned, our conclusion (Way2Go) is that expertly designed instructional units, sound active-engagement lessons, and good teaching are as important as whether a lesson is cast as inquiry or direct.

References


Way2Go project materials are available at: www.wmich.edu/way2go/ (project funded by the National Science Foundation’s Interagency Education Research Initiative (IERI/NSF 04-553) Award #0437655. Any opinions, findings, conclusions or recommendations in this paper are those of the authors and do not necessarily reflect the views of the NSF.)
IMPACT OF THE GROUPS ABILITY COMPOSITION ON ACADEMIC PERFORMANCE IN COOPERATIVE LEARNING

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Abstract

Two hundred thirty-six students in 12th grade physics classes participated in a quasi-experimental study comparing homogeneous and heterogeneous grouping in a jigsaw classroom. Students were assigned to expert groups according to prior topic knowledge. Written helps, as well as review and comprehension questions with solutions were offered in order to support students with gaps in prior topic knowledge. The study is based on a context oriented approach: The content “motion of electrons in electric and magnetic fields” is embedded in a context with highly motivating potential, that is the scanning electron microscope. Across all participants, students showed higher intrinsic motivation, activated deeper level processing strategies, and performed better on their expert topic when working in homogeneous groups. Self reported quality of communication was identified as partial mediator between expert group composition and academic performance.

1. Background, Framework, and Purpose

An impressive body of research shows that cooperative learning methods can foster positive outcomes ranging from increased motivation to improved academic achievement (Slavin et al., 2003). An important factor for fruitful cooperative working is the composition of the groups (Lou et al., 2000). From a cognitive perspective the assignment by ability or prior knowledge is of high interest. One main research result is that neither form of ability grouping is uniformly superior for promoting the achievement of all students (Saleh et al., 2005). As a striking disadvantage of homogeneous grouping a detrimental impact on performance of low ability students was found (Lou et al., 1996).

In order to address this problem, we conducted a study based on the jigsaw learning technique, a widely used method that first was proposed by Elliot Aronson et al. (1978) in the 1970s. This form of group work involves students switching between different groups. Students meet first with other students who have been assigned the same subtopic in an „expert group“. Together they research their subtopic, discuss, and clear up questions. Subsequently, these expert groups break up and the students recombine with experts from other subtopics to form the “jigsaw groups”. Each student in each group then teaches the whole group about his or her expert subtopic, thus covering the whole topic.

The jigsaw method combines two key elements that must be present for students to be successful in a cooperative learning environment, that is, individual accountability and positive interdependence (Antil et al., 1998): due to task-specialisation each group member is accountable for a unique part of the activity and the students in the jigsaw groups are dependent on their experts’ knowledge (“resource interdependence”). Furthermore, students in the expert groups are aware of the demand to teach their peers in the jigsaw groups (“teaching expectancy”).
2. Methods

2.1 The lessons

Our study is based on a learning unit, which was selected by the following criteria: it had to be possible to divide the material into independent segments in order to conduct the jigsaw classroom, and the degree of difficulty had to be adapted to the students’ capabilities. Furthermore, the topic had to be meaningful – that is, important for the 12th grade level – as well as interesting. Following Häussler (1987), boys as well as girls of all ages from 11 to 16 years have a higher than average interest in the topic ‘Structure of matter’. Thus, gaining insight into the microworld by suitable apparatuses seems to be a favourable topic for a multitude of students. Hence, it was suggested to take the topic ‘Principles of the scanning electron microscope’ as the learning context. This topic is particular favourable for teaching physics at the 12th-grade level, since the underlying physical principles (motion of charged particles in electric and magnetic fields) covers a main area of the syllabus. In order to foster the interaction with the learning material, we adapted the MURDER-Script (Dansereau, 1988). The learning unit as well as the cooperation script are described elsewhere (Berger & Hänze, 2008).

2.2 Participants, experimental design, and procedure

Twenty-two 12th grade physics classes participated in the study, conducted in the 2005-2006 and 2006-2007 school years. The analyses are based on 263 students without missing data. The actual learning unit was made up of four school hours. First, basic information on motion of electrons was introduced in two physics hours through direct instruction by the teachers. At the end of the first lesson, the questionnaires capturing intrinsic motivation and cognitive activation were given as a pretest measurement. In the next two physics hours (in a double period), students worked in the jigsaw classroom. For cooperative working, the study topic was divided into four, self-contained and comprehensible segments. The posttest on academic performance was given in an extra lesson some days after the learning unit.

2.3 Independent variable

In our study we experimentally investigated the effect of the expert groups’ composition on different outcome measures. As composition criterion the results of the pretest were used. The pretest was designed highly topic related. Based on the results of this pretest, the students were assigned to two grouping patterns:

- Students with similar prior topic knowledge scores (Homogeneous groups)
- Students with a broader range of prior topic knowledge scores (Heterogeneous groups)

Each of the participating classes were randomly assigned to one of these treatment conditions.

3. Results

3.1 Academic performance

The effects of group composition were analyzed by an univariate analysis of covariance with prior topic knowledge (high/medium/low) and experts’ group composition (homogeneous/heterogeneous) as factors. We revealed a significant main effect for group composition ($F(1,174)=21.70, p<.001$) with medium to large effect size ($\text{Cohen's } d=.63$) and a marginally significant interaction between prior topic knowledge and experts’ group composition ($F(2,174)=2.84, p = .061$).

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5 For all calculations the pretest score was used as covariate.
3.2 Learning experience

With regard to intrinsic motivation and activation of deeper level processing strategies we run univariate analyses of covariance with prior topic knowledge and experts’ group composition as factors. For both variables, corresponding pretest measures were used as covariates. For quality of communication we conducted an univariate analysis of variance as no covariate was available for this variable. The measurement point in time for the three self report scales was after working in the expert groups. The calculation revealed main effects for intrinsic motivation \(F(1,174)=5.09, p=.025, d=.28\), activation of deeper level processing strategies \(F(1,174)=4.29, p=.040, d=.26\), and quality of communication \(F(1,175)=9.92, p=.002, d=.40\) in favour of homogeneous group composition. No significant interaction between prior knowledge and experts’ group composition was found for intrinsic motivation \(F(2,174)<1, p>.50\), activation of deeper level processing strategies \(F(2,174)<1, p=.42\) as well as quality of communication \(F(2,175)<1, p>.50\).

4. Conclusions and Implications

Regarding academic performance, in our study we found the overall effect that students profit from working in groups which are homogenous with respect to prior topic knowledge. This general finding is in accordance with the meta-analysis conducted by Lou et al. (1996). But, by contrast, the effect size we found is medium to large, that is, highly relevant to pedagogical settings. Why is it that students performed much better in homogeneous groups? We found an advantage of homogeneous grouping with respect to the quality of communication as well as motivational and cognitive variables.

In our study we introduced a highly relevant composition criterion for learning success: The learning unit was essentially based on topic knowledge, accurately captured by the pretest measurement. That is, in homogeneous groups students shared a well defined, common base of prior topic knowledge, which is highly relevant for successful performing the task. Thus, new information could be acquired more effectively. The activities might be carried out more smoothly with fewer stops to help students who were not on a par with the rest of the group (Lawrenz & Munch, 1984). Thus, homogeneous groups may foster learning as students are able to maintain a pace commensurate with other group members (Lou et al., 1996). The better interaction in homogeneous groups was accompanied by activating more individual high level processing strategies as well as higher intrinsic motivation. Both effects should be favourable for successful learning.

5. Bibliography


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6 Due to the small number of studies on science education included in the meta-analysis we discuss our study in light of the overall results reported by Lou et al. (1996).


A DIDACTIC PROPOSAL FOR THE VISUAL TEACHING OF THE THEORY OF RELATIVITY IN HIGH SCHOOL FIRST COURSE

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Abstract

This paper presents an innovative approach to enlighten students attending first year High School Physics and Chemistry courses (16 years old) on the qualitative aspects of Einstein’s Theory of Relativity. This is being done in the scope of setting the foundations for a later comprehension of the quantitative contents of the Theory, within the curricula of the second year. This new approach is founded on Minkowski’s geometrical formulation of the Theory of Relativity. We have added to this instructive display a visual inference of the Lorentz transformation, as well as a representation of the mass-energy equivalence by showing a comparison of the graphs resulting from a non-elastic collision. Following the description of the operational model, some examples are presented, as well as the consequences of its implementation in the classroom.

Introduction

The experimental design of the investigation is sketched in Table 1. Its type can be described as pretest-posttest-posttest without a control group. Reasoning and action schemes that students are able to activate during the deployment of the programmed activities were elaborated and analysed throughout the different phases of the investigation (Domínguez et al, 2003; Rumelhart and Ortony, 1982). The proposal itself became the independent variable along the investigation.

Table 1. Experimental design of the investigation

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>The sample is adjusted to the new methodology</td>
<td>Initial characterisation of the sample</td>
<td>Implementation of the didactic proposal in the classroom</td>
<td>Final characterisation of the sample</td>
</tr>
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</table>

In Phase 1 a didactic proposal on Galileo’s Relativity was presented to the classroom with the aim to acquaint students and teacher with the new methodology. In phase 2 the sample was initially presented (18 students of High School First course) in order to measure their level of knowledge prior to the implementation of the instruction proposal. In Phase 3 the didactic proposal Einstein’s Theory of the Special Relativity was developed. In Phase 4 the final mastery of the students was assessed and contrasted with their previous notions. Finally, a statistical analysis was fulfilled to audit the significance of the knowledge improvements obtained through the learning protocol.

An analytical method was used to probe the experimental data. It was based on a qualitative diagnosis about the activity and reasoning schemes that were activated by the students for the description, explanation and prediction of the proposed facts, phenomena and situations.
Rationale

The usual mathematical demonstration of the Theory of Relativity involves too many difficulties at the academic level of a High School student.

Minkowski (Sazinov, 1990; Mermin, 1997) proved that all the physical outcomes of the Theory were of a geometrical nature, and as such could be formulated in a four dimensions spacetime. In this proposal, we have extended the field of applications of Minkowski's diagrams in two senses:

- In order to build the Theory itself in a visual way starting from the same principles that were used by Einstein: relativity and the conservation of the speed of light.
- As a way to envision the mass-energy equivalence by the use of an analogy: the graphic analysis of a non-elastic collision.

This also allowed us to introduce the Theory in a qualitative and visual way in early courses:

- To direct a larger number of students towards the comprehension of the Theory of Relativity. Even for those that will not follow higher degrees in education,
- To provide students with a larger base for the later study of the quantitative aspects.

The teaching methodology employed is based on the ability that the spacetime diagrams have, which allows the qualitative explanation of many concepts of the Relativity Theory while retaining all its quantitative power, due to the fact of being geometrical figures.

We can put together the time and space axis in the same figure, thus obtaining a “spacetime diagram” (figure 1). In these diagrams some physical magnitudes can be observed and measured, like (obviously) space and time or speed (shown like arrows in the figure). It must be kept on mind that the left, vertical arrow doesn’t represent any movement. It would suggest the time elapsed (clock) without displacement of the object (tree). This is a definition of the State of Rest.

The figure also shows that the slope or angle of the arrow (or line) represents the displacement of an object (bicycle) as time passes by. That way, a sloped arrow (or line) means movement, and the tilt of the line would be an indication of the speed rate of an object.

The space-time diagrams can be used to measure an unknown mass. In that purpose we incite an inelastic collision against another known mass in such a way that they both move against each other at the same speed. If both were of equal mass, the set won’t move after the collision (a vertical line in the spacetime diagram).

In figure 2 the masses of the car and the bicycle are different, and after the collision, the car will drag the bicycle towards the right. If we extend backwards in time the line of the set after the collision, the centre of mass will be shown shifted towards the car, an indication that its mass is bigger than the bicycle one.

Once shown how to physically understand the spacetime diagrams, we have to set up its main symbolic unit: the cell unit.

Given that the Theory of Relativity considers the speed of light in a particular way, we will choose the units for the space and time, where the light speed (c) is one. Given that light travels 300,000 km in one second, we can choose as unit a tenth of a second for time, which means that the space through which lights travels will be of 30,000 km. In this case we will have a cell unit suitable for the analysis of the signals broadcasted from the satellites that beam the GPS Galileo system, located at an orbit around earth with a radius of similar value (figure 3). The
diagonal dotted line indicates a signal send to earth from the satellite at light speed. Spacetime is covered by an
infinite number of these unit-cells, the same way as tiles over a wall.

In figure 4 we apply the Galileo transformation (that is an inclination of the time axis while the space axis is
kept unaltered in a horizontal position) from the Earth reference system (grey squares) to the figure that explains the
functioning of the GPS. As this system is based in signals sent from satellites positioned on an orbit circling the
Earth, unmistakably above the atmosphere, these signals will travel through the space vacuum, which means that its
speed should be affected by the Galileo transformation.

As a consequence, due to the different speeds of the signals, now there will be a space
Earth has moved during of 0.1s. But we know that orbiting around the Sun. If
direction there shouldn’t be the figures resulting from at any time. But the earth
revolves around the Sun along the year, which means that after six months it will be moving in the opposite
direction, signifying that the location is continuously changing within a 3km radius along the year and it would be
impossible to obtain a better accuracy than 3km with a GPS device.

The fact that the GPS accuracy is of a few meters and that no corrections or adjustments due to the Earth
movement are needed, corroborates the null result obtained by Michelson in his well-known experiment.

If Earth would not move through the space as is stated by the Geocentric Model this would be in accordance with the expected results. But by the time when Michelson made his test, this Ptolemaic system was no longer valid.

Resulting from the above, we can see in figure 5 that there is an unresolved disagreement between the Galileo transformation (a horizontally based parallelogram) and the light pathway (dotted line).

When we consider that the Galileo transformation is at the base of all the Newtonian mechanics, and that the speed of light (and all the electromagnetic waves) makes the core of the electromagnetic theory, we find that these results put both theories, the richest of Classical Mechanics, in an overt opposition against each other.

This was the situation at the dawn of the Twentieth Century.

After several attempts to find an explanation to Michelson’s outcome, it was finally Lorenz who put forward an innovative approach to the spacetime transformation where the speed of light was kept unchanged. This new approach is shown in figure 6 as a 45º slope rhomb.

As in the Galileo transformation the surface of the rhomb is the same of the original square. In order to achieve that, one of the diagonals is lengthened while the other is shortened in an equal amount. Given that the surface of the rhomb is half the product of its diagonals, the result is the same.

Three elements in this figure must be highlighted:

- Although one of the diagonals is lengthened more than the other, the light speed is the same in both. It must be remembered that the speed is shown by the slope and that both diagonals have the same 45º slope.
- The main difference with Galileo's transformation is that, in this case, the base is no longer horizontal but slopes in the same sense as the side of the square. It is precisely in this fact that the un-intuitive elements of the Special Theory of Relativity are based.

- In the Galileo's transformation there was an invariable line: the horizontal. As a consequence time was absolute, the same for the whole Universe. The Lorentz transformation shows a different invariable: all diagonals. That way a new absolute shows in the Universe: the speed of light.

Once the geometric form of the Lorenz transformation is established, we will find out which are its outcomes when dealing with the same physical magnitudes as above.

Now, as shown in figure 7, the measure of time is not the same in the original frame of reference as it is in the transformed one. Time in a moving FR is slower, a phenomenon called time dilation, which is the first of the four relativistic effects that we are trying to exemplify. It is interesting to emphasize that the figures not only show a qualitative image of this effect (and the later), but they can also be used in the founding of numerical values. In this case, comparing both scales we can see that 6 units of time in the new FR are equivalent to 7 in the original FR, that is to say: time has expanded in 7/6. This value coincides with the outcome that would result from a mathematical handling.

By applying similar considerations to figure 8 we can examine the experience of space contraction by which the lengths of a moving system are smaller than in a state of rest. It's important to emphasize that, in this case, the longitude of a ruler means the measure of the horizontal distance between its both ends, which would generally result in two lines with the same slope. In this case, they will be coincident to the lateral limits of the unit cell, both in the case of the square as in the rhomb (Lorentz transformation).

In the following diagram (figure 9) we can observe the relativistic effect of the limiting speed. Many people know somehow that the speed of light cannot be exceeded, but only a few would know why. Sometimes it is thought that it's only a current limit due to our nowadays' technical restraints, similar to what it used to be, a few decades ago, with the sound barrier, and that further technological progress will allow us to go beyond the known limit. It is also thought that science doesn’t have the specific instrument that could allow the measure of speeds beyond 300,000 km/s and so it is taken as an immeasurable speed in its own. In the figure we can grasp the reality and characteristics of such a limit.

While the reference system increases its speed, the left side increases its slope. Due to the shape of the Lorentz transformation, the base of the figure also slopes upwards in an equal proportion. As a result, both lines will merge towards the dotted diagonal (speed of light). But we also know that the rhomb limiting both lines has to keep a constant surface, so that no matter how much is the rhomb stretched, it will never totally close or collapse. As a result, it is impossible for any frame of reference to reach the speed of light relative to others.

In order to appraise the effect of Lorenz transformation upon a mass, we look at figure 10, representing an inelastic symmetric collision. It shows that the speed attained by both masses is represented by the vertical dotted line, indicating a state of rest (which responds to the fact that the situation is completely symmetric).
Let’s now have a look to the same event, but in a frame of reference that moves together with the right hand mass, that is to say, half the speed of light to the left (figure 11). To solve it we apply the Lorentz transformation to the square at the start and draw the lines between the due points (lower vertexes and midpoints at the sides). At a first look we confirm that the line of the right hand mass is now vertical, meaning that from the new frame of reference, this one doesn’t move, which is exactly what we expected. We also notice that the centre of mass, which in the previous example was steady, is now moving to the right at half the speed of light, as was also expected.

The most important feature results by applying a horizontal line in the lower part of figure 11. Now we can see that the centre of mass is no longer located at the middle point between the two masses, which is an indication that “something” pushes the centre of mass left wise.

The present situation is no longer symmetric, since the mass on the right side doesn’t move any longer, which means it hasn’t got any kinetic energy, while the left one moves faster than before, that is to say it’s got kinetic energy. It can be graphically shown that the amount of kinetic energy of the left mass is equal to an additional mass that would shift the centre of mass to the point where it is presently located. This is the relativistic phenomenon known as the mass-energy equivalence, that can be shortened by stating that energy has the same inertial characters as mass or that mass and energy are two forms of the same physical property. We can express this result by the following equation that seems to be almost trivial: E = mc².

If we consider that to be able to change the mass and energy units we must multiply by the square of a speed, and that in the diagrams we used the speed of light is the unit (c = 1) we can rewrite the equation this way: E = m c². Finally, for a light speed different to the unit, the equation becomes: E = mc² which is the well known Einstein equation, considered to be one of the most mysterious and hard to understand in Physics, and that we can now figure out as a geometric outcome of the Lorenz transformation.

Methods

The model established by Domínguez et al. (2007) was used as a basis for the design, planning and development of the educational proposal. That model comprises the following assignments:

- Assessment of the academic content; valuation of learning problems’ burden; selection, formulation and progression of objectives;
- choice of teaching strategies and design and sequence of activities; and appraisal of evaluation strategies.

The first stage allowed us to sort out, systematize and settle on a sequence the topics to be learnt, founded on the analysis of the current Galician curricula (XUGA, 2008) and their epistemic appraisal. This enabled us to elaborate the action and reasoning schemes that are considered as schemes of reference, moreover as the suitable level of knowledge from the school sciences point of view.

Considering the level desired for Sciences students, we designed a scheme of thought named “Einstein” and shown in figure 12.
Figure 12: “Einstein” scheme of thought

In this referential scheme we can distinguish a main sub-scheme (Minkowski’s space-time), two previous sub-schemes (Michelson and Lorentz) which have their own structure and that are not expressed in the referential, and four sub-schemes (time, space, speed and mass) where each of them have also their own structure, revealed in this case only in part for each of them by means of relations of image, of comparison, of denomination, of verification and of explanation, that will be exemplified for the case of the “speed” sub-scheme:

Image relations: as is shown in the figure, a proper mental picture of speed in the space-time requires the measurement of the horizontal displacement during the time unit.
Comparison relations: while representing the speed in the Lorenz transformation we find that the velocities don’t add-up horizontally like in the Galilean case, but they evolve towards the diagonal line (dotted line) in an asymptotic way (never reaching it).

Denomination relations: the fact that even with a succession of speed boosts it would be impossible to attain the speed of light is called “finite speed of light” which is one of the relativistic concepts that we seek to present in a qualitative way by means of this task.

Verification relations: the impossibility to attain the speed of light is constantly confirmed in particle accelerators.

Explanation relations: the fact that no material entity is capable of moving at a speed greater than the speed of light makes it possible to understand why the Universe, according to the Big Bang theory-, has a limited size, given that no galaxy can be parting away from us at a speed faster than the speed of light.

Regarding the second task, we thoroughly went through the available bibliography, a move that enabled us to foresee the learning difficulties in connection to the Theory of Special Relativity (Table 2).

<table>
<thead>
<tr>
<th>Concept</th>
<th>Students ideas</th>
<th>Bibliography</th>
</tr>
</thead>
<tbody>
<tr>
<td>System of reference</td>
<td>Rest is considered an “undeniable” state in itself. It was shown that the visual explanation helped in elucidating the issue.</td>
<td>Hewson, P.W., 1982</td>
</tr>
<tr>
<td>Spacetime</td>
<td>Resistance to consent that time or length measures are tied to the system of reference. An “immutable” nature is assigned to measuring values obtained within a system of reference in relation to the observer.</td>
<td>Villani and Pacca, 1987</td>
</tr>
<tr>
<td>Speed of light</td>
<td>The impossibility to surpass or even to reach the speed of light is taken as the result of present day technical limitations that prevent us going beyond. Galileo’s sum of velocities is given credit.</td>
<td>Villani and Arruda, 1998</td>
</tr>
</tbody>
</table>

Table 2: Some learning difficulties to be expected

The third task concerns the integration of the analyses of the academic content with the learning difficulties. This provides the selection and formulation of possible learning objectives.

The implementation of the fourth task allowed us to select the teaching strategies and to model a sequence of nine learning activities. Table 2 shows two examples of such activities.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Concise description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity nº 4. Lorentz transformation</td>
<td>The analysis is done in an entirely visual way, using the same spacetime graphs and the visual display of the Physics’ concepts that allowed us to establish the form of Galileo’s transformation in activity nº 2. However, now, instead of the common sense, we applied the notion of the speed of light conservation.</td>
</tr>
<tr>
<td>Activity nº 5. Consequences of Lorentz transformation</td>
<td>This activity analyses in a systematized way the physical implications of Lorentz transformation. This is done without overlooking the qualitative vision that defines these activities.</td>
</tr>
</tbody>
</table>

Table 3. Educational activities

The activities are put forward as pragmatic problems (Jiménez 1998; García et al., 2000) in the scope of promoting discussion and interchange. They are arranged in small teams of students, seeking to reproduce the social nature of science (Reigosa and Jiménez 2000). This contributed in building a classroom ambience suitable for the debate and discussion of ideas.
Finally, in the fifth task, evaluation strategies were chosen that were subsequently integrated to the actual learning process. They result from the analysis of educational activities and imply the current evaluation standards of the official curricula (XUGA, 2008).

Results

Throughout the execution of the proposal, it was found that the students’ arguments converge towards proper interpretations in accordance with the relativity theory. Spacetime diagrams make up an efficient didactic tool for the understanding of the relativity theory concepts. In the explanatory process, the students put into effect new reasoning skills, including the relationship between relativity theory concepts and the implications learnt from the visual application, thus filling them with full significance. The students schemes were graded by levels (i: initial; f: final; r: retention after a year; g: general).

Table 1 shows the way by which the thinking schemes of tested students were structured for the three different phases (i, f, r). Each capital letter represents a student in the group. In the initial characterization (i) almost the whole group of students is placed at the lowest level, which corresponds to expectations, given that the Theory of Relativity was not explained to them in previous courses. In the final characterization, after four weeks of training, a conspicuous increase of levels is perceived, emphasizing the fact that almost a quarter of the sample attained f5 level, corresponding to what would be expected for school sciences. In the retention phase the students show a downgrading of levels, due to the loss of information retained in the short term memory and as such, of little significance. Considering that the retention test was done after a year without any additional instruction on the Theory of Relativity, the downgrading is considered adequate.

<table>
<thead>
<tr>
<th>Levels g</th>
<th>Levels i</th>
<th>Students N=24</th>
<th>Levels f</th>
<th>Students N=24</th>
<th>Levels r</th>
<th>Students N=23</th>
</tr>
</thead>
<tbody>
<tr>
<td>g5</td>
<td>f5</td>
<td>B,D,F,K,L,R,Y</td>
<td>r5</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g4</td>
<td>f4b, f4a</td>
<td>A,G,H,M,S,T,V,X</td>
<td>r4</td>
<td>D,F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g3</td>
<td>f3b, f3a</td>
<td>I,N,O,P,U,W,Z</td>
<td>r3b, r3a</td>
<td>A,B,C,G,H,O,R,X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g2</td>
<td>i2b, i2a</td>
<td>F,U</td>
<td>f2</td>
<td>C</td>
<td>r2b, r2a</td>
<td>E,I,K,T,U,W,Y</td>
</tr>
<tr>
<td>g1</td>
<td>i1b, i1a</td>
<td>A,B,C,D,E,G,H,I,K,L,M,N,O,P,R,S,T,V,W,X,YZ</td>
<td>f1</td>
<td>E</td>
<td>r1b, r1a</td>
<td>N,P,S,V,Z</td>
</tr>
</tbody>
</table>

The class exhibited a lofty degree of satisfaction all along the activities. The reason being the enhancement of the students’ ability to ponder over concepts generally admitted as difficult to understand.

Conclusions and Implications

The visual methodology could be used with larger efficiency if incorporated at earlier courses of sciences and mathematics by the adjustment of the current curricula contents (spacetime graphics, changes of origin, geometric transformations).

A systematic use of Minkowski spacetime graphs as a visual didactic tool would allow the inclusion of General Relativity subjects also in a qualitative form in High School courses.
A leap forward is requested to secure quantitative results, and it doesn't seem to be loaded with excessive difficulties. It is hoped that the methodological approach being submitted in this paper would help in its introduction in the second course of High School.

**Acknowledgement**

To the Spanish Agency for International Cooperation (AECI), Project A/019399/08

**References**


Abstract

On the background of what H. F. Mikelskis and I considered to be necessary, and also due to explicit wishes of our science teaching students, we developed an elective course with a strong focus on two common phenomenological approaches to science teaching: The pedagogy of Martin Wagenschein and Waldorf-style phenomenon oriented science teaching. We introduce the course, explain the approach briefly, and present a qualitative study with the participants of our last course to evaluate their experiences and potential benefits during the course. Another point in question was how their experiences with alternative ways of teaching affects their beliefs and attitudes towards science teaching and how they assess the practicability of such approaches. We reflect the results with respect to both the German and the American national standards of science education.

Introduction

From high school to university conventional approaches to building knowledge in physics follow a well established scheme: We give evidence for some first principles (e.g. Newton’s Laws, Maxwell Equations etc.), express them in highly abstracted formulas, and apply those principles mathematically to a set of canonical problems (e.g. harmonic oscillations, electric fields of a charged ball etc.). Empirical studies (cf. Merzyn 2008) show that most of the high school students tend to get lost in such a world – physics is unpopular and dropped as early as possible, the content is learned mainly as a phrase, if anything, and soon forgotten.

Possibly even worse, this picture of an analytic-deductive physics shows a lopsided picture of what physics is and how it works. Physics is experienced as a variety or branch of mathematics and doing physics involves more or less complicated text book problems and some canonical experiments that support the particular content. The completely different nature of scientific thinking within actual research – and the spirit of doing research as well – seems to be missing. But have the teachers ever experienced physics in that way?

Understanding Physics – and Teaching to Understand

Our German students went through an education in physics which is widely experienced as boring, narrow-minded, ineffective and uninspiring. In their academic way they learn about “real” physics and professional teaching but little or nothing about how to make physics teaching more interesting, vivid and enriching. On the other hand it is a well known fact that the student’s attitude towards physics strongly depends on the personality and performance of the teacher (Muckenfuss 1995). While our students typically share at least some of the negative experiences within the usual physics education any ambition “to do better when I will be a teacher” fizzles out within a professional education that presents physics and physics teaching in much the same unfortunate way.

As the persons in charge for an elective module on teacher professionalization, H. F. Mikelskis and I decided to try to improve that situation. From our biographical background we were clear about where to start: For both of us our own pedagogical practice was strongly inspired by phenomenological approaches to science teaching.
precisely we chose the pedagogy of Martin Wagenschein (Wagenschein 1981, 1998) and emergence- or phenomenon oriented physics (Maier 1993, Mackensen 1998, Theilmann 2007) as paradigms. Both methods focus on connecting experience and individual conceptualization, had noticeable impact in the German school practice, and inspired the academic dispute (Redecker 1995, Nölle 2007; Grebe-Ellis & Theilmann 2006). They attach importance to the point of genuine understanding: the learning process is targeting not primarily standardized facts, formulae, and skills of handling them but a sensible conception of the scientific content. This conception ideally emerges from a self-conducted explorative process and is not necessarily of any canonical form (Theilmann 2008). Both methods allow an autonomous learning process that transforms “unscientific” and immediate experiences in a sensible way into scientific concepts or quantitative arguments. This takes its time – and such an approach therefore conflicts with the limited extent of lessons available or more comprehensive curricular requirements. In other words: they usually have to be implemented in an exemplary way.

The Course

The course had three consecutive lessons per week over one term and twelve participants (with an overall study year of about 15 students). It is an eligible part of the Potsdam Bachelor study program for physics teachers with alternatives e.g. in astronomy or computational science. The course is therefore the only didactical choice available and the recommended time is the beginning of the third study year.

The first sessions were introductory and contained exercises in observing basic (but surprising and unknown) optical phenomena such as “looking through pinholes” or “bright shadows” (cf. Maier 2004). Each student chose a project where a central concept of the theoretical framework or a classical example of “understanding-oriented” treatment of a physical content was to be presented. The range of worked topics was from elementary static, optics, or astronomy over philosophical background to the idea of “explorative experimenting” (Steinle 1998). Each project was presented to the course with emphasis both on theoretical embedding and presenting interesting and enthusing experiences.

The students had to write a concluding report of about twenty pages. In their reports, the students should reflect on the received theory and methodology. Furthermore, it was a motive for deeper reading, and the place for documentation of the practical work or the experiments that were done. We encouraged explicitly creative, non-standards forms of execution such as fake newspaper articles or virtual interviews with the departed players of the theoretical discussion – and a couple of students indeed took this opportunity.

Evaluation of the Course

The label „Phenomenology“ stands for a wide variety of methods and attitudes within science and science teaching (see Østergaard, Dahlin & Hugo 2008). In our context we refer to “phenomenological science teaching” as a method that builds on direct experiences, sensible understanding of phenomena and avoids formal or mere mathematical arguments.
Due to our “monopoly position” within the Bachelor student’s curriculum we expected the participants of the course to represent a more or less typical cross section of students. However, with such a specialized course profile it is far from clear that the students appreciate our offer. Furthermore, it was an open question whether the course can indeed deliver at least some of the benefits for practical teaching mentioned above. In the second year we therefore decided to evaluate the course results based on a questionnaire, documented dialogue and the written reports of the students. We addressed the students motivations, expectations, their experiences during the course, their personal benefits and resumes, but also their view of problems and the potentials around phenomenological approaches to science teaching. The sample is small – we finally involved eight students in the study, about half of our study year.

Expectations before the course

As pointed out above all of our undergraduate students looking for an elective on the didactical field will consider our course. We asked for their expectations and their previous knowledge regarding phenomenological approaches to science teaching. The main results are:

- No student had special expectations with respect to phenomenological science teaching,
- the motivation for choosing the course was merely practical or profession related.

Some quotes:

“[We expected the course to be] mainly practical…”

“It was the less physical choice…”

“The course was recommended from friends and I wanted to extend my science teaching skills!”

Experiences during the course

To reflect the students experiences during the course we asked for their workload, how serious they took the project, how they compare their experiences to experiences from other courses, for self-assessment of what was learnt and whether the presented material was informative and methodologically appropriate. The main results are:

- All students found the course profitable but
- primarily due to their project work and not due to the lectures.

The workload was generally considered to be adequate but probably higher than in concurrent courses. It was generally agreed that the individual project work and the presentations revealed or presented new and relevant aspects of science teaching. The applied methods (group work, text work, group experiments) were considered as adequate and appropriate.

An interesting remark addresses the scheme that the rating is done with 2/3rd on the report and 1/3rd on the oral presentation:

“…but I found the afterwards rating of our reports somehow inappropriate. I'd prefer a portfolio which documents the evolution of thinking over the course.”

Outlook
To learn something about if and how the course affected self-concept and professional attitude we asked whether we met their expectations (if any), whether they felt encouraged for their teaching, whether they got new insights, incentives or stimuli, which methodical elements from phenomenological teaching will enrich their future practice, how they assess the practicability of alternative approaches to science teaching, and whether they will pursue the introduced new methods further. The main results are:

- 2/3rd of the students felt explicitly encouraged to teach physics, none discouraged,
- all students found valuable practical and/or methodical elements for their future practice,
- 2/3rd made new positive experiences that changed their attitude towards physics or physics teaching.

Some characteristic quotes:

“In the course they showed me a different kind of physics than I had met at school…”

 “[I realized that] Physics is everywhere and doesn't need special instruments…”

 “I learned that if I am enthusiastic enough [about a physical topic] I will get others into it…”

 “I shall not take the physics out of textbooks but rather look into nature…”

Generally the course met the few expectations students had in advance. There were generally positive and some enthusiastic votes regarding the encouraging effect of the course. Some students explicitly appreciated the examples from everyday experience or nature. Another rather positively experienced point is the phenomenological attitude of not arguing formally but demonstratively “on the things that can be seen” – connected to the feeling to “really understand” the particular effect and delivering new insights on rather common effects.

On the other hand the students clearly distrust the possibility of realizing such “sensible physics teaching” in their future practice because they feel cramped by official parameters and curricular requirements. Also it was expressed that their experiences on that new field were too cursory to build a self-contained practice – and that the topic should be treated less marginally in the general teacher training.

Doing Phenomenological Teaching and Science Education Standards

How does such an approach to teacher professionalization fit into the picture of the increasing standardization of science education? The answer obviously depends on a national perspective since Science education standards are national frameworks for the improvement of science teaching. Their concrete implementation depends strongly on the particular understanding of what “improvement” might be. We outline two answers to our question that highlight two rather different profiles, the German “Bildungsstandards” (BS Physik 2005) and the American “National Science Education Standards” (NSES 1995).

Doing Phenomenological Teaching and the German Science Education Standards

The German standards for science education reflect two characteristic features of the German situation of education system: The federal structure of the country – where school teaching and teacher education is in the responsibility of the federal states – and the high level of attention the public pays to the performance of primary and secondary students in international test on school knowledge such as TIMSS or PISA (PISA 2009, TIMMS 2009). For the major subjects the conference of federal school ministers elaborates a set of papers that define standards of knowledge and skills (“Kompetenzen”) on different class levels. Among the explicit goals of the process they explicitly mention an increased competitiveness of German students. For physics the reference are the
standards for class 10, however, the same principles are used in motivating and formulating e.g. high school graduation tests (“Abitur”) etc. So far there are no standards for teacher training or professionalization.

The Standards are organized in skill areas (Kompetenzbereiche) with associated skill levels. For each skill area the skill levels are defined by lists of characteristic general abilities. The different skill areas are

- Subject matter knowledge (“Fachwissen”): Knowing physical phenomena, concepts, principles, facts and laws, being able to allocate them to the basic concepts (see below).
- Communication: Accessing and exchanging information on physical subjects.
- Assessment of scientific issues (“Bewerten”): Identifying physical issues in different contexts and assessing them.

The physical content is organized along a set of basic concepts (matter, interaction, system, energy) that should encourage and improve cumulative learning etc. Textbooks and testing focuses on subject matter knowledge.

It is rather obvious that phenomenological learning in principle covers all skill areas but suffers from the method’s exemplary nature. Such a method cannot guarantee neither a certain, i.e. predefined range of known content nor practical or methodological knowledge of the students.

Doing Phenomenological Teaching and the American Standards of Science Education

The National Science Education Standards (NSES) are “a vision of learning and teaching science in which all students have the opportunity to become scientifically literate”. The underlying concept of scientific literacy has a long – and controversial – history in America (Bybee 1997, 2002) and distinguishes more or less distinct levels of scientific skills:

- Nominal scientific literacy: Formal, merely lexical and superficial/incorrect knowledge of (a subset of) scientific concepts and terms.
- Functional scientific literacy: Coherent formal knowledge of important scientific terms and concepts.
- Conceptual and procedural scientific knowledge: Autonomous and correct applying scientific concepts or procedures in standard or non-standard contexts.

The mantra of the NSES – “science as inquiry” – is a concise paraphrase of this highest level of scientific education. Its implementation in a number of standards – actually accounts towards the attitude of teachers (and not standard requirements of student knowledge!) – is widely independent of particular curricular guidelines. Indeed, the teaching standard A2 can be read in a natural way as a call to arms for phenomenological teaching, while the standard B3 reads like a summary of Wagensein’s “Socratic method”. Standard D advocates “extended investigations”, “flexible” (”, “safe”) and “supportive environments of science inquiry”, encourages the use of

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2 “Teachers of science plan an inquiry-based science program for their students...“

3 “Teachers of science guide and facilitate learning. In doing this, teachers focus and support inquiries while interacting with students, orchestrate discourse amongst students, challenge students to accept and share responsibility for their own learning...“

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resources outside the school and engaging students in the design of their learning environment. Last, standard E4 addresses issues like the respect for diversity of “ideas, skills and experiences” or the conditions and modalities of science as a social process.

Conclusions and Outlook

A modern understanding of scientific knowledge – as reflected in national standards of and the discourse in science education – spans from knowing “relevant” facts and practices over knowledge about technological and environmental aspects to being able to communicate and assess scientific results etc. Practical teacher education is less versatile as such an understanding of science and it is an continuous challenge to provide an education that meets a satisfyingly wide range of those goals. Our attempt to confront ongoing teachers with methods and examples of phenomenological teaching targeted the integration of subject matter knowledge within examples of concrete phenomenological inquiry. Those examples are designed to make both the content and the process of learning transparent and demand an involvement of students beyond correctly reproducing formal knowledge.

Our study tried to throw light on the impact of such an approach with respect to self-concept, attitude, and self-confidence of our students. We show indications of a positive development of self-concept and self-confidence for the majority of the participants. Even more, for some participants the investigative and exemplary style of phenomenological teaching made enough sense to initiate integration of particular ideas or methodology into the individual world view – in other words: a shift in the attitude towards teaching. On the other hand, student express that they feel a discrepancy between actual (or “official”) school practice and such attitudes towards teaching – which is certainly the case. The gap between conventional and phenomenological teaching is in many ways considerable and we see just reflections on a first contact between the two worlds. A central motive both in Waldorf and in Wagenschein pedagogy is the important role of “understanding” science. The course could deliver to some extend a new, inspiring way of thinking about – and understanding of – nature. Of course, it is totally open whether this experiences can be transformed into a successful individual classroom practice of our students.

Another question had to be whether phenomenological teaching fits into the overall picture of science teaching. The inspections of the content and the framework of national science education in Germany and in the US yields two completely different pictures. The output-orientation (in the sense of preparing students to be successful in typical international test on scientific content) of the German standards leaves little room for anchoring phenomenological teaching institutionally. Within the framework of the NSES phenomenological teaching can be legitimated in a quite natural way. And: Given that the understanding of scientific knowledge behind the German and the American definitions of education standards do not differ substantially this implies that phenomenological teaching complies indeed with a modern reading of science.

The presented result will be directing the further development of the elective course. We will further investigate the individual experiences and “transformations” of our students within the course. The main focus will be to show, discuss, reflect and evaluate the different sorts of conceptualization within phenomenological teaching and to make the students develop examples of such teaching that can really be productive for their professionalization.

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4 “Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.”

5 This statement corresponds both to the fact that in Germany phenomenological teaching is a rare exception and the feeling of the study participants that it might be difficult to practice it…
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ASTRONOMY EDUCATION IN SCIENCE EDUCATION

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Abstract

Astronomy education has an important place in science education since it can be easily observed by daily events. However, there are not any various materials beyond the basic models (such as solar system). The purpose of this study is to develop some materials about basic astronomy subjects for 7th graders based on constructivist science teaching. Initially the literature was reviewed depending on the scope of the astronomy unit in 7th grade and materials were developed accordingly. Materials are composed of simple activities, experiments accompanied with working sheets and some models about the moon, the sun, the constellations, the universe, the black holes, the spacecrafts and etc. After revising the materials, they were given to students in an original teaching session in order to see their efficiencies. In the research, the pre-test post-test experimental model with a control group was used. The results showed that, the materials developed are effective on 7th grade students’ understanding of the astronomical subjects.

Introduction

In our age, new technologies are produced and new knowledge is added to the old ones every passing day. As a result it gets quite impossible to teach those by means of just transferring. For this reason we should stop teaching by transferring the knowledge but base teaching to make the students have the skills to reach the knowledge. Astronomy is one of the recurrent contemporary issues in the mass media where news related to comets, new stars, satellites, space tests, etc., frequently appear. Astronomy searches out very important questions that human being has wondered for many many years such as “How the universe occurred? How will the universe end? How the life began on Earth? Is there any similar life in universe?” (Astronomi yıllık broşürü, 2009). In this context astronomy education has an important place in science education since it has both daily events and observable effects. However, there are not any various materials beyond the basic models (such as solar system).

Because of this, students at all levels are especially motivated to work in astronomy education. Nevertheless, the students’ interest, together with all the information they get from different sources, doesn’t increase their knowledge about the most elementary and common aspects of these subjects. On the contrary, alternative conceptions are frequent. There are several studies about these alternative conceptions in astronomy especially emphasizing on the students’ alternative understanding of astronomical concept in a scientific manner. For example, students think that universe is a meteor, the sun is not a star, the earth is bigger than the sun (Klein, 1982; Ekiz & Akbaş, 2005), and orbit is the same as direction (Ekiz & Akbaş, 2005). In the study conducted by Martinez Pena and Gil Quilez (2001), it was found that students frequently confused the positions of the full moon and the new moon, sometimes, because they consider the phases to be fixed (a new Moon on the left and a full one on the right), independent of the relative position of the Sun.
The purpose of this study is to develop some materials about basic astronomy subjects for 7th graders based on constructivist science teaching and the find out the effects of teaching with these materials on students’ attitudes towards science and academic achievements. The sub-problems of the research are as follows:

1- Is there any significant difference between experimental and control group students’ academic achievement towards astronomy unit regarding before and after the teaching?

2- Is there any significant difference between experimental and control group students’ attitudes towards science regarding before and after the teaching?

Methods

The model of the research

This study searches for the effectiveness and effects of developed materials about basic astronomy subjects on the attitudes and achievements of the students towards science and astronomy. Moreover, the correlation between the students’ attitudes towards science and achievements towards astronomy was analyzed.

Some of the materials were taken from the material development study of Ergin and others (2005). In their works it is stated that some materials about 6th grade astronomy unit were developed but the effectiveness of these materials were not searched out. Also, their materials were not enough for our work regarding the content area because of mainly two reasons. First, they were developed under the previous science curriculum (MEB, 2000) whereas we studied the current science and technology curriculum (MEB, 2005). Second, due to the curriculum, their content was held for 6th grade but we studied the 7th grade in the current curriculum. Therefore, in addition to their materials we developed others and also made some revisions of the materials that Ergin and others developed (2005) depending on the current curriculum content and grade level.

Materials are composed of simple activities, experiments accompanied with working sheets and some models about the moon, the sun, the constellations, the universe, the black holes, the spacecrafts and etc. During the material development process pilot studies were drawn with around twenty 7th grade students from different primary schools. After revising the materials, they were given to students in an original teaching session in order to see their efficiencies. In the research, the pre-test post-test experimental model with a control group was used. Quasi-experimental model was followed because of using the arithmetic mean of the students for designing the control and experimental groups.

Lessons in control group were taught by question-answer techniques and teacher and class book centered lesson plans which were prepared according to classical learning model. In control group, teacher centered classical learning model, in which the teacher is active and the student is passive in class experience and in educational activities in that those experiences are given, was performed. The experimental group was applied developed astronomy materials for 4 weeks.

Data collection instruments

In this study, “Attitude Scale towards Science” developed by Geban and others (1994) and “Astronomy achievement test” developed by researchers were used in order to determine the achievements of the students towards astronomy. “Attitude Scale towards Science” consisted of 15 items with Cronbach’s Alpha reliability coefficient of 0.94.

Astronomy achievement test was developed by Ergin and others (2005). The test has Kuder Richardson Reliability coefficient of 0.68 and consisted of 20 items.
Analysis of data

The data gathered from the attitude scales and the achievement tests were initially coded, then analyzed by using SPSS 11.0 Statistics program. Mann Whitney U-test for Independent Samples and Wilcoxon Signed Rank Test for Paired Samples were applied in order to determine the difference of the attitude and achievement scores of the control and experimental groups.

Results

Before and after treatment, The Achievement scale was administered to experimental and control groups. Each correct response in the scale was scored as one point. Comparisons were made in terms of the experimental and control groups’ pre-post test achievement score means with Mann Whitney U-test.

Table 1. Comparison of mean scores of control group (CG) and experimental group (EG) in astronomy achievement scale given as a pre-test

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>18</td>
<td>18.64</td>
<td>335.5</td>
<td>159.5</td>
<td>p&gt;.05</td>
</tr>
<tr>
<td>CG</td>
<td>18</td>
<td>18.36</td>
<td>330.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 show that there was no statistically significant difference between the mean scores of students in control and experimental group with respect to Astronomy Achievement Scale before the instruction. Consequently, the two groups were equivalent on this dependent measure. Thus, students in the both groups had similar knowledge about astronomy topic which was examined in this study.

Table 2. Comparison of mean scores of control group (CG) and experimental group (EG) in astronomy achievement scale given as a post-test

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>18</td>
<td>22.14</td>
<td>398.5</td>
<td>96.5</td>
<td>P&lt;.05*</td>
</tr>
<tr>
<td>CG</td>
<td>18</td>
<td>14.86</td>
<td>267.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at the .05 level

It is seen from Table 2 that there was a statistically significant difference between the mean of score of the students instructed by developed materials and that of the students taught by traditional method in favor of experimental group. We can conclude that the achievement of these students increases with the prepared materials and activities.

The experimental and control group pre and post test scores were compared within Wilcoxon Signed Rank Test for Paired Samples (Tables 3-4).

Table 3. Comparison of mean scores of experimental group in astronomy achievement scale given as pre and post-test

<table>
<thead>
<tr>
<th>Pre-post test</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Row</td>
<td>12</td>
<td>6.5</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive Row</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>3.074*</td>
<td>p&lt;.05</td>
</tr>
<tr>
<td>Equal</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on positive row
It is seen from Table 3 and 4 that the achievements of the students at the experimental group increased as compared to ones before the application, not significant increment was observed at the achievements of students at the control group as compared to ones before the application.

Before and after treatment, the science attitude scale was administered to experimental and control groups. Each response in the scale was scored as likert type. Comparisons were made in terms of the experimental and control groups’ pre-post test attitude score means with Mann Whitney U-test.

**Table 5. Comparison of mean scores of control group and experimental group in science attitude scale given as a pre-test**

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>18</td>
<td>17.11</td>
<td>308</td>
<td>137</td>
<td>p&gt;.05</td>
</tr>
<tr>
<td>CG</td>
<td>18</td>
<td>19.89</td>
<td>358</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5 shows that there was no statistically significant difference between the mean scores of students in control and experimental group with respect to science attitude scale before the instruction. Consequently, the two groups were equivalent on this dependent measure. Thus, students in the both groups had similar attitudes.

**Table 6. Comparison of mean scores of control group and experimental group in science attitude scale given as a post-test**

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>18</td>
<td>25.69</td>
<td>462.5</td>
<td>32.5</td>
<td>P&lt;.05*</td>
</tr>
<tr>
<td>CG</td>
<td>18</td>
<td>11.31</td>
<td>203.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at the .05 level

It is seen from Table 6 that there was a statistically significant difference between the mean of score of the students instructed by the developed materials and that of the students taught by traditional method in favor of experimental group. We can conclude that the attitudes of these students increase with the prepared materials and activities.

The experimental and control group pre and post test scores were compared within Wilcoxon Signed Rank Test for Paired Samples (table 7).

**Table 7. Comparison of mean scores of experimental group in science attitude scale given as pre and post-test**

<table>
<thead>
<tr>
<th>Pre-post test</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative row</td>
<td>18</td>
<td>9.5</td>
<td>171</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive row</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>3.73*</td>
<td>p&lt;.05*</td>
</tr>
<tr>
<td>Equal</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on positive row
### Table 8. Comparison of mean scores of control group in science attitude scale given as pre and post-test

<table>
<thead>
<tr>
<th>Pre-post test</th>
<th>N</th>
<th>Average of row</th>
<th>Sum of row</th>
<th>z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative row</td>
<td>4</td>
<td>2.5</td>
<td>10.0</td>
<td></td>
<td>.707*</td>
</tr>
<tr>
<td>Positive row</td>
<td>1</td>
<td>5.0</td>
<td>5.0</td>
<td>.707*</td>
<td>p&gt;.05</td>
</tr>
<tr>
<td>Equal</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Based on positive row

It is seen from Table 7 and 8 that the attitudes of the students at the experimental group increased as compared to ones before the application, not significant increment was observed at the attitudes of students at the control group as compared to ones before the application.

## Conclusions and Implications

The results of this research which was conducted in order to determine the effects of developed materials on 7th grade students’ achievements of the astronomical subjects and attitudes of science education are as follows:

- Before the beginning of the research, it was found that there was no significant difference between the experimental and control groups students’ achievements of the astronomical subjects and attitudes of science education. Therefore, the levels of both groups were assumed equal at the beginning.
- The experimental group students achieved more than the control group students did. The experimental group students’ achievements are positively affected by the developed materials.
- The experimental group students have more positive attitudes towards science than the control group students have. The experimental group students’ attitudes are positively affected by the developed materials.
- No significant change is observed in the achievement of control group students towards science.
- No significant change is observed in the attitudes of control group students towards science.

These results showed that, the materials developed are effective on 7th grade students’ understanding of the astronomical subjects.

When the astronomical concepts which are abstracts for the students are thought with models, experiments, games and computer aided aided activities are effective on their attitudes towards science courses and academic achievements.

When the science and technology curriculum is examined it was seen that neither there is much emphasis on the astronomical subjects nor there are activities supporting those subjects. In this context, the in-service training courses for teachers about astronomical subjects may help teachers about how to help students for a better construction of subjects mentally. It is suggested that the curriculum of teacher training faculties should be revised for giving some courses about material development including astronomy.

Besides, some observatories may take place both in schools and teacher education faculties in order for students to examine and make concrete those abstract objects.

This study might be reconducted on a wider sample with more experimental and control classes.

## References


EDUTAINMENT SOFTWARE USED IN COMPUTER ASSISTED LEARNING IN CELL DIVISION TOPIC

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Karadeniz Technical University

Abstract

In this study, it was aimed to investigation of effectiveness of edutainment software used in computer assisted teaching in comparison to traditional teaching method on students’ achievement, misconceptions and attitudes toward biology on the issue of cell division. In this quasi experimental type study, there were two chosen groups and each of these groups consisted of 24 students accepted as one treatment and one control group according to the results of pre-studies. The treatment group was instructed by edutainment software through computer assist while the control group was instructed by traditional methods. To measure students’ academic achievement cell division achievement test (CDAT), to identify the misconceptions the cell division concept test (CDCT) and to determine the attitudes toward biology lessons biology attitude scale (BAS) was applied. While the collected data evaluated there can be seen that edutainment software had the positive effect on to the students’ achievement, reduced the existing misconceptions and changed attitudes toward biology in positive way, however did not sufficient about exactly disappearing the misconceptions by oneself.

Introduction

Today’s information and communication technologies can be applied to science education. Among these technologies, the use of computers is the most popular and well known in educational settings. Computer-assisted instruction (CAI) plays an important role in contemporary teaching and learning of science concepts (Chang, 2001). The teachers can use computers at different times and places according to the characteristics of the subject matter, the students, and the available software and hardware (Aşkar & Usluel-Kocak, 2002). With CAI, there is a form of one-to-one instruction, plus the opportunity for the students to proceed at their own pace, repeating parts of the exercise as they wish. In addition, there is added variety and, perhaps, novelty in CAI, along with the potential to use vivid and animated graphics, enabling three dimensional aspects, and other features to be viewed more realistically. Of course, not all computer programs have these features, but the potential is certainly there (Morgil et al., 2005).

The major classifications of CAI lessons include tutorials, drill and practice, simulations, and instructional games (Alessi & Trolip, 1985). A number of other classifications, such as problem-solving and inquiry lesson designs have been discussed, but the overwhelming majority of CAI lessons fall within the previous four classifications. Each basic design provides a unique method for using the computer to teach, reinforce, practice, or apply information. In many cases, various design combinations, called hybrid designs, are developed to utilize the advantages and, in some cases, to minimize the disadvantages, of each design option (Hannafin & Peck, 1988).

“Edutainment”, is a hybrid genre that relies heavily on visual material, on narrative or game-like formats, and on more informal, less didactic styles of address (Buckingham & Scanlon, 2000). The purpose of edutainment is to attract and hold the attention of the learners by engaging their emotions through a computer monitor full of vividly colored animations. It involves an interactive pedagogy and, totally depends on an obsessive insistence that learning is inevitably “fun”. McKenzie (2000) states another term “technotainment” which he defines as technology heavily laced with entertainment but essentially lacking in rigor or value. Technotainment often stresses technology for
technology’s sake without enhancing student reading, writing and reasoning skills. Similarly, “edutainment” suggests overtly entertaining learning materials, which contain messages addressed to both parents and children. Through explicit educational claims, edutainment software encourages the parents to believe that this software is beneficial in developing children’s skills in a variety of subjects. They also raise learners’ expectations that learning can be enjoyable and fun.

Rationale

Edutainment software programs are forms of CAI that have the following additional attributes: motivation, reward (feedback), interactivity, score, and challenge. Support also exists for these specific types of CAI and its effectiveness in the classroom (Vogel et al., 2006). However, it remains unclear as to whether or not learning through edutainment instructional software program will improve upon traditional teaching results. The aim of this study is to identify any possible difference in students’ achievement, misconceptions, and attitudes towards biology when the subject of cell division is taught by the edutainment software program in biology education.

Methods

Sample of Research

The sample of this study consisted of sixty grade 9 students (aged 15 to 16 years) from one high school. The sample was randomly assigned into two groups, experimental (n = 24) and control group (n = 24). Both groups received an equal amount of instructional time and were taught the same instructional content.

Research Design

A pretest–posttest control-group design (Campbell and Stanley, 1966) was adopted. The participants in both groups were tested before and after a 2-week intervention. The experimental group students were taught by edutainment software program, whereas the control group students received a traditionally designed instruction. Both groups received an equal amount of instructional time and were taught the same instructional content.

Research Instruments

The cell division achievement test, the cell division concept test and the biology attitude scale were used in the study.

Cell division achievement test (CDAT)

To measure students’ cell division achievement, a cell division achievement test (CDAT) was developed by the author of this study and its content validity and reliability were checked by applying guidelines described previously (Black, 1986; Davis, 1988; Haladyna, 1994). The test content and objectives were determined according to the Ministry of National Education’s high school curriculum. The CDAT items were selected from the textbooks and preparation books written for the University Entrance Exam. There were 24 multiple choices type items in the test. The items were based on the following categories: the purposes of mitosis, mitosis and the cell cycle, the stages of mitosis, the results of mitosis, the purposes of meiosis, meiosis and the sexual reproduction, the stages of meiosis, the results of meiosis, the division of the cytoplasm, prokaryotic cell division mechanism, the comparison of mitosis and meiosis. The reliability of the test (r = 0.81) was determined by using the Cronbach’s alpha.
Cell Division Concept Test (CDCT)

A written test was designed to ascertain students’ misconceptions about cell division. The cell division concept test (CDCT) was modified on the basis of review of related literature (Lewis et al., 2000). The set of questions was designed to probe the student’s understanding of the processes, purposes, and products of cell division. The set of the questions was divided into two parts. Part 1 was focused on mitotic cell division through a consideration of the production of skin cells. Part 2 was focused on meiosis through a consideration of the production of an egg cell. In each part, students were asked to compare the chromosome number and genetic information in the original and the new cell, identify where in the body this type of cell division takes place and say whether or not such cell division also occurs in the plants. The reliability coefficient of this CDCT computed by Cronbach’s alpha estimates of internal consistency was found to be 0.76. The frequency of responses to each question were noted, together with the types of reasoning used to justify each option, and the frequency with which each type was used. Furthermore, in order to make a more detailed comparison into the students’ understanding of cell division, their misconceptions were identified by their reasoning’s to the questions.

Biology attitude scale (BAS)

Canpolat’s (2002) attitudes scale was adapted as biology attitude scale (BAS) in this study to assess the sample’s (participants’) attitudes towards science lessons. 15 sentences occurring in a Likert-type scale and with five alternatives were given students to determine their ideas about the biology lesson. In these sentences there were positive and negative statements. In the scale, positive statements were scored as 1, 2, 3, 4, and 5 according to its grade. Negative statements were scored as 1, 2, 3, 4, and 5 according to its grade. BAS was given at the beginning and end of the implementation to the two groups. The internal consistency reliability of the scale was found to be 0.798.

Procedure

The Bioscopia edutainment software program used computer assisted learning method applied in the experimental group. Bioscopia is a role-playing science adventure game. The student’s mission is to rescue a young scientist. To complete the mission and escape from Bioscopia, students have to learn about biology and apply that knowledge to solve Bioscopia’s clever puzzles. Students must search the disabled, abandoned laboratories, solve biology puzzles and eventually create the antibiotic that will ultimately save the biologist. Student will need knowledge of Human and Cell Biology, Genetics (including cell division), Botany and Zoology to solve the puzzles and unlock doors that will lead the student to be a young scientist. It’s not that the puzzles themselves are that hard to solve; there is help available in the science tutor that features all the answers to the questions and is a presentation of hundreds of fascinating facts and concepts of the biology.

Experimental group had their instruction in the computer laboratory. Students in experimental group worked individually in a computer lab without any guidance or help from the instructor who was also the researcher. Students in experimental group followed the instructional program as projected to a screen from the teacher’s personal computer as well as their own computers. The teacher made a brief introduction about the subject that going to be learned and simply presented the contents of the lecture. Then, the students were left to work alone, with minimal interference from the teacher who was present only to respond to questions raised by individual students.

The control group was given a traditionally designed instruction, which is a dominant approach in contemporary Turkish Educational System. In the control group, the teacher-directed strategy was used as traditional instruction. The teacher used lecture and discussion methods to teach photosynthesis. The students were required to read the related topic of the lesson from the textbook before lecture. The teacher described and defined the issues and afterward, students were engaged to discussion through teacher-directed questions. The major part of
Instruction time (70–80%) was devoted to instruction and engaging in discussions stemming from the teacher’s explanation and questions.

Data Analysis

To measure the possible differences on students’ achievement a cell division achievement test, to assess the possible differences on sample’s attitudes towards biology lessons biology attitude scale, to ascertain students’ misconceptions about cell division cell division concept test was used before and after the instruction. With the assistance of SPSS 13.0 package program, independent sample t-test applied to the data that was collected from cell division achievement test and biology attitude scale. The student’s responses to each question placed at the cell division concept test were assessed according to the response types and the frequencies were revealed.

Results

Students’ Achievement

As seen in Table 1, at the beginning the pre-test means of experimental group and control group was 7.833 and 7.083, respectively. These results showed that the sample’s present knowledge levels were very close to each other and there was not a statistical difference between the groups (t = 0.586, p > 0.05). At the end of the treatment, the post-test scores were 13.333 and 10.041 for two groups. A statistical significant difference was found between experimental group and control group (t = 2.874, p < 0.05). This means that edutainment software program was more effective at cell division achievement in experimental group than control group.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Groups</th>
<th>Numbers of students</th>
<th>Means</th>
<th>Standard deviation</th>
<th>t-test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>Experimental Group</td>
<td>24</td>
<td>7.833</td>
<td>3.985</td>
<td>0.586</td>
<td>0.561</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>24</td>
<td>7.083</td>
<td>4.835</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test</td>
<td>Experimental Group</td>
<td>24</td>
<td>13.333</td>
<td>3.252</td>
<td>2.874</td>
<td>0.006*</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>24</td>
<td>10.041</td>
<td>4.572</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p<0.001

Students’ Attitudes

The means related to biology attitude of the two groups before the treatment were 70.05 and 69.83, and there was not statistical significant difference between the two groups (t = 0.077, p > 0.05). The post-test scores were 89.16 and 78.16 after the treatment and there was a statistical difference between experimental group and control group (t = 2.287, p < 0.05) (Table 2). These results illustrate that the edutainment software program influences students’ attitudes towards biology lessons in a positive way.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Groups</th>
<th>Numbers of students</th>
<th>Means</th>
<th>Standard deviation</th>
<th>t-test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>Experimental Group</td>
<td>24</td>
<td>70.05</td>
<td>10.21</td>
<td>0.077</td>
<td>0.939</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>24</td>
<td>69.83</td>
<td>9.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test</td>
<td>Experimental Group</td>
<td>24</td>
<td>89.16</td>
<td>9.01</td>
<td>4.178</td>
<td>0.000*</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>24</td>
<td>78.16</td>
<td>9.22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p<0.05
Misconceptions

Before the implementation, we looked at percentages for each question in the pre-test. There was not much difference between the groups in terms of their prior knowledge and misconceptions. For example, the first question, “How many chromosomes would be found in the egg cell?”, as percent in experimental group and control group was 62.5% and 62.7, respectively. After the implementation, some of the related concepts are examined in detail.

**Misconceptions about chromosome number**

Students were asked to give their responses to the question “How many chromosomes would be found in the new skin cells?”. The students’ responses indicated that they held misconceptions about chromosome number (Table 3): 54.1% in the experimental group and 62.5% in control group. After the treatment, the students’ responses indicated that their misconception dismissed in experimental group and 12.5% in the CG.

**Misconceptions concerning genetic information after cell division**

The results in Table 3 showed that students had a misconception that “after mitosis new cells contain different genetic information”. The rate of misconceptions is in experimental group and control group was 33.3% and 25%, respectively. After the treatment, the rate of misconception decreased to 12.5% in the experimental group and 12.5% in the CG.

**Misconceptions related to the location of cell division**

Students were asked to give their responses to the question “Which of the following parts of the body would divide by mitosis or meiosis?”. The misconceptions were grouped into two categories as “mitosis occurs in gonads” and “meiosis occurs in somatic tissues” in Table 3. The pre-test results showed that students had misconception at the rate of 25% and 33.3% in the experimental group, 20.8% and 29.2% in the control group. After treatment, the rate of misconceptions decreased to 8.3% and 16.7% in the experimental group, 16.7% and 16.7% in the control group, mitosis occurs in gonads and meiosis occurs in somatic tissues respectively.

**Misconceptions about cell division in plants**

Students’ awareness that the mitosis or meiosis also takes place in plants was probed using the question “Does the same type of cell division, for the same purpose, occur in plants?”. The misconceptions were grouped into two categories as “mitosis does not occur in plants” and “meiosis does not occur in plants”. The pre-test results showed that students had misconception at the rate of 45.8% and 45.8% in the experimental group, 50% and 37.5% in the CG. After treatment, the rate of misconceptions was 33.3% and 50% in the experimental group and in the 37.5% and 50% in the CG (Table 3).

**Conclusions and Implications**

Computer-assisted instruction is a widely studied and supported method of teaching. Numerous meta-analyses and review articles have been published showing positive effect sizes supporting CAI over the other teaching methods on student’s academic achievement (Bayraktar, 2000; Christmann & Badgett, 2003; Fletcher-Flinn & Gravatt, 1995; Kulik, 1994; Lowe, 2001; Powell et al., 2003; Soe, Koki, & Chang, 2000; Tsai & Chou, 2002). The findings of this study concerning the effects on students’ achievement are consistent with the ideas of the previous reports. It was revealed in the study that the experimental group at photosynthesis achievement was more successful than the CG after the treatment.
The significant academic achievement of the students in the experimental group could be explained by the fact that the edutainment software program created a learning environment in which students can learn at their own pace. Interactive teaching makes students more aware of their own knowledge. Edutainment software program appeared to make students more active, compared with being passive recipients of knowledge as in control group.

Table 3 Results of pre and post-test concerning misconceptions.

<table>
<thead>
<tr>
<th>Categories and misconceptions</th>
<th>Pre-test %</th>
<th>Post-test %</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental Group</td>
<td>Control Group</td>
<td>Experimental Group</td>
<td>Control Group</td>
</tr>
<tr>
<td>Chromosome number</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after mitosis the chromosome number would double</td>
<td>33.3</td>
<td>33.3</td>
<td>0</td>
<td>4.2</td>
</tr>
<tr>
<td>after mitosis the chromosome number would halve</td>
<td>20.8</td>
<td>29.2</td>
<td>0</td>
<td>8.3</td>
</tr>
<tr>
<td>after meiosis the chromosome number would remain the same</td>
<td>29.2</td>
<td>25</td>
<td>12.5</td>
<td>33.3</td>
</tr>
<tr>
<td>after meiosis the chromosome number would double</td>
<td>33.3</td>
<td>41.7</td>
<td>16.7</td>
<td>16.7</td>
</tr>
<tr>
<td>Genetic information after cell division</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after mitosis new cells contain different genetic information</td>
<td>33.3</td>
<td>25</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>after meiosis sex cells contain same genetic information</td>
<td>37.5</td>
<td>33.3</td>
<td>29.2</td>
<td>20.8</td>
</tr>
<tr>
<td>Location of cell division</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mitosis occurs in gonads</td>
<td>25</td>
<td>20.8</td>
<td>8.3</td>
<td>16.7</td>
</tr>
<tr>
<td>meiosis occurs in somatic tissues</td>
<td>33.3</td>
<td>29.2</td>
<td>16.7</td>
<td>16.7</td>
</tr>
<tr>
<td>all cell division occurs in somatic tissues</td>
<td>25</td>
<td>20.8</td>
<td>4.2</td>
<td>16.7</td>
</tr>
<tr>
<td>all cell division occurs in gonads</td>
<td>12.5</td>
<td>12.5</td>
<td>0</td>
<td>4.2</td>
</tr>
<tr>
<td>Cell division in plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mitosis does not occur in plants</td>
<td>45.8</td>
<td>50</td>
<td>33.3</td>
<td>37.5</td>
</tr>
<tr>
<td>meiosis does not occur in plants</td>
<td>45.8</td>
<td>62.5</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Many studies have been implemented about the influences of computer based instructions on students' attitudes. Students do not agree whether it makes positive changes in attitudes towards science and science lessons (Mitra, 1998). For example, Selwyn (1999) reported that computer assisted material develops a positive attitude towards science education. In contrast to this, Shaw and Marlow (1999) suggested that computer assisted material do not show a positive effect on students’ attitudes. Besides, students’ attitudes towards science are quite negative if traditional teaching methods are used in science classes (Colletta & Chiappetta, 1989). In this study, edutainment software program was more effective than CG on student’s attitudes.

Edutainment software program provided “more student-centered learning”, teaching students how to learn by themselves. Implementations provided by software program require students to work at their own pace through a structured set of learning experiences. Edutainment software program was able to present text and graphic materials to students in a coordinated manner, and questioning techniques means that the learners were active during the learning process.
Misconceptions are very important during the learning processes of individuals. It is well known that it is not easy to eliminate the misconceptions by just employing traditional instructional methods. One of the alternative ways of overcoming this problem may be using computer assistant materials in science classrooms (Çepni et al., 2006). In the present study, Edutainment software program provided better learning environments for students to understand cell division with respect to control group. Experimental group at building cell division concepts were more helpful than the control group after the treatment. However, this study revealed that there were still some misconceptions in the experimental group even after the treatments. These misconceptions were generally related to the abstract concepts as energy sources for plants and their nutrients and thus to visualize and conceptualize them is difficult for students. This shows that misconceptions may be reduced and/or dismissed if teaching–learning activities are given at comprehension and application levels (Karamustafaoğlu et al., 2003).

It is critical that lessons are planned in such a way so as to concentrate using the computer assisted materials on the topics in a lesson that will help to computer-based learning. Having an entire teaching module on a CD-ROM with multimedia assets are more effective to improve student’s academic learning. Keeping the balance between the educational content and computer entertainment is critical to realize desired educational goals. Otherwise, changing students’ attitudes towards science lessons without improving academic achievement will be distant from the purposes of CAI. It can be concluded that edutainment software program used computer assisted learning could improve student achievement, some extent change misconceptions, but it is very difficult to argue that it can change students’ attitude toward science lessons in a short time.

References


TEACHER PEDAGOGICAL CONTENT KNOWLEDGE AND
STUDENT UNDERSTANDING IN “RESPIRATION”

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Universiti Pendidikan Sultan Idris

Lilia Halim & Kamisah Osman
Universiti Kebangsaan Malaysia

Abstract

This paper present case studies designed to explore how teacher express their pedagogical content knowledge in teaching respiration, the reason of practicing that PCK and the component of PCK that promote to student understanding. Components of PCK related to promoting students’ understanding include a sound content knowledge of the teacher, ability to provide hands-on learning activities and providing examples. Teachers tend to not develop their PCK further because of their view a) of the need to cover the syllabus on time for examination, b) of high achieving students preferring to direct teaching compared to active learning and c) of their lack of understanding of their content knowledge and ability to communicate in English well.

Introduction

In order to facilitate students’ understanding, teachers must have well-developed knowledge base for teaching, including knowledge of multiple instructional representations and the connections between them (Moseley & Brenner, 1997; NCTM, 2000; Rider, 2004; Wilson, Shulman, & Richert, 1987).

Shuman (1986, 1987) highlights one type of knowledge that teacher needs and that is pedagogical content knowledge (PCK). PCK is one type of teachers’ knowledge specially possessed by teacher for transforming subject matter knowledge into forms that are more accessible to students. PCK emerged from the combination of subject matter knowledge and pedagogical knowledge.

Pedagogical content knowledge is a special combination of content and pedagogy that is uniquely constructed by teachers and thus is the "special" form of an educator’s professional knowing and understanding. PCK known as craft knowledge, comprises integrated knowledge representing teachers’ accumulated wisdom with respect to their teaching practice: pedagogy, students, subject matter, and the curriculum. Shuman (1987) further proposed several key elements of pedagogical content knowledge: knowledge of representations of subject matter (content knowledge); understanding of students conceptions of the subject and the learning and teaching implications that were associated with the specific subject matter; and general pedagogical knowledge (or teaching strategies). To explain what he called the knowledge base for teaching, he included other elements: curriculum knowledge; knowledge of educational contexts; and knowledge of the purposes of education.
Teacher who possesses this knowledge might be able to delineate what is easy or difficult for students to learn, and how to organize sequence and present the content to accommodate the diverse interest and abilities of the students. In order to foster students’ conceptual understanding, teachers also must have rich and flexible knowledge of the subjects they teach. They must understand the central facts and concepts of the discipline, how these ideas are connected, and the processes used to establish new knowledge and determine the validity of claims (Anderson, 1989; Ball, 1990; Borko & Putnam, 1996; McDiarmid, Ball, & Anderson, 1989).

The development of PCK is influenced by factors related to the teacher personal background and by the context in which he or she works. PCK is deeply rooted in the experiences and assets of students, their families and communities. Grossman (1990) suggested that possession of the knowledge described within PCK was anticipated as having the greatest impact on teacher’s classroom actions. Science teachers make instructional decisions that greatly impact the learning of their students. Some of these decisions pertain to the modification of curriculum, while other decisions may involve the presentation of science. Such decisions are largely influenced by their PCK. This type of knowledge allows teachers to reason pedagogically and to make decisions pertaining to practice that ensures students will develop an understanding of science.

Rationale

PCK illustrate how subject matter of a particular discipline is transformed for communication with learners. Its includes recognition of what makes specific topics difficult to learn, the conceptions students bring to the learning of these concepts, and teaching strategies tailored to this specific teaching situation.

In context of teaching biology, the greatest challenge that teachers face in biology is to help students learn physiology of human body and to keep abreast of all the current knowledge especially in the area of cell and molecular biology. However, students bring ideas of their own about the human body with them to the classroom. Many of these notions are at odds with scientifically acceptable conceptions about how the body works and can be surprisingly resistant to correction by conventional approaches to teaching (Wandersee, Mintzes, and Novak, 1994). These misconceptions can also arise during the course of instruction, as students continue to build their understanding of the subject during lectures and laboratory activities. These are some of the dilemmas and challenges to biology teachers. How to deliver the overcrowded syllabus and at the same time need to achieve desired examination results, while in the process truly educating students?

Thus, PCK is seen as a critical element for effective teaching of biology. In fact, PCK has been described as a knowledge base necessary for effective teaching in many educational reform document (NBPTS, 2004). NBPTS emphasized the need of teachers to have PCK, knowledge about student and the abilities to engage students understanding (Park and Oliver, 2007).

As PCK deals with the “specific why and how to” of teaching a given discipline – in this case teaching respiration. Respiration have been chosen to be study in this research because teaching cellular respiration found difficult because students often do not understand molecules that they cannot see. There also a lot of misconception found in this topic all around the world, especially student cannot differentiate between respiration in plant and photosynthesis in plant. Student also believe that animals breathe in oxygen and breathe out carbon dioxide, while plants breathe in carbon dioxide and breathe out oxygen. Fisher & Lipson (1986).
Purpose of study

The purpose of this qualitative case study is to investigate:

1. How do teachers express their pedagogical content knowledge (PCK) in “Respiration”?
2. Why do teachers express that PCK in teaching “Respiration”?
3. What components of teachers’ PCK promote students understanding in “Respiration”?

Methods

Case study method is employed in this study. Five biology teachers who are currently teaching form four biology from different secondary schools in Malaysia and their students are purposely selected to be the respondents in this study. Data collection method used in this study was classroom observation using a checklist created by the researcher; personnel field notes diary; interview with the teacher and the students and concept map constructed by the teacher.

Research procedure start by interviewed the teachers before they teaching “Respiration” to elicit their idea about the topic, teaching preparation and PCK then follow by classroom observations. The frequency of observations are according to the frequency of the class done by the teacher. After the observation researcher also interview the teachers and the student to get deeper idea about PCK. Interview of the teachers focusing about why they express that PCK to teach “Respiration”, what are the aspect influence their justification and also what are the component of PCK that help to promote student understanding. The interview to the student have been done as the triangulation to the data of how their teacher express their PCK in the classroom to teach “Respiration” and also to know what are the factor that promote their understanding. The teachers also asked to construct a concept map to demonstrate their understanding or content knowledge of “Respiration”.

Preliminary findings and discussions

Respondents express their PCK in “Respiration” differently. The experience teachers demonstrate that “Teachers must know the whole topic and not compartmentalize to help student understand the topic”. On the other hand, novice teachers blame on the lack of facilities and teaching time, thus they are unable to express better PCK in the classroom. Novice and experienced teachers often use PowerPoint slides in representing their content and just emphasize on the key points of a lesson to overcome their problem in content knowledge and their ability to teach biology in English. In other words, they do not elaborate their teaching of the concepts with analogies or examples.

Teachers also believe that the high achieving students prefer direct teaching rather than doing activities in class. Therefore, teachers feel unnecessary to provide hands on activities in illustrating a concept. Teachers also believe that the used of power presentation will overcome their problem of not doing the experiment in laboratories due to the lack of laboratory facilities.

There is however a contrast in the students’ data. The students prefer active learning, they prefer doing activity rather than listening to the explanation itself. However, students are respectful of teachers who have a lot of knowledge and who are able to give an effective explanation. The students also emphasize that they prefer many examples since it makes them understand better.

It appears that teachers with better PCK i.e. providing more hands on learning experience, providing effective explanations and many examples can promote better understanding among the students. This notion is supported by the students’ needs and views. Limited PCK is due to inadequate understanding of the content knowledge and inability to express oneself in English, which is the current medium of instruction in science in Malaysia. Thus, teachers resort to only drawing upon the available teaching resources i.e. power point slides provided by the Ministry of Education and not developing their PCK.
Conclusions and Implications

To teach all students according to today's standards, teachers indeed need to understand subject matter deeply and flexibly so they can help students understand the ideas, relate one idea to another, and re-direct their thinking to create powerful learning. Teachers also need to see how ideas connect across fields and to everyday life. Language also play a big role in teaching, the lack of language competencies effect the PCK used by the teacher in the classroom. These are the building blocks of pedagogical content knowledge.

References


OUR EXPERIENCE IN TRAINING MEDICAL STUDENTS IN PATHOLOGICAL PHYSIOLOGY

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Abstract

Pathological physiology, as a discipline in medical training, takes place in premedical course and it is the binding link between basic and clinical sciences. It studies the mechanisms of etiology and the pathogenesis of diseases. Therefore it requires a sufficiently profound mastery of the theoretical material and the acquisition of skills for logical thinking. Pathological abnormalities occurring in various diseases are studied by using as a basis the knowledge for the proper functioning of a healthy body. Not without significance is also the acquisition of a set of practical skills, which is gained during the practical exercises. Our experience shows that more effective and detailed mastering of the material was observed when using a combination of different methods, which include both classical lectures, educational films that introduce the etiology and pathogenesis of some basic pathological processes or diseases (shock, myocardial infarction, etc.) and others, which require the active participation of students, i.e. tests, research papers preparation, problem cases discussion, seminars and colloquia on various sections of the material and last, but not least – the practical work during the exercises.

Introduction

Pathological physiology, as a discipline in medical training, takes place in premedical course and it is the binding link between basic and clinical sciences. It studies the mechanisms of etiology and the pathogenesis of diseases. Therefore it requires a sufficiently profound mastery of the theoretical material and the acquisition of skills for logical thinking. Pathological abnormalities occurring in various diseases are studied by using as a basis the knowledge for the proper functioning of a healthy body. Not without significance is also the acquisition of a set of practical skills, which is gained during the practical exercises.

The pathophysiology education is associated with accumulation of many skills: knowledge, critical thinking, self-directed learning, communication, interdisciplinary collaboration, and research (Baldwin et al., 2002). Many clinical researchers have to possess a complex set of interlocking skills – clinical, scientific, technical, research and development, problem-solving and managerial. The object of training programs is to provide the knowledge and skill base to equip scientists with graduate qualifications in a basic science to make a safe and effective contribution to health care (Quality Assurance Agency for Higher Education, 2004).

The training in pathological physiology in medical schools in Bulgaria is conducted in two semesters in the 3rd year of education – during the fifth and sixth semesters, after having completed a study of general human physiology. In the first semester the common pathological processes such as inflammation, fever, allergy, immunity and more are considered. Through the second semester the students study the disturbances that occur in different systems (cardiovascular system, respiratory system, etc.).
Rationale

Achieving the goals in pathophysiology education requires the use of many and various teaching methods, both during the lectures and during the practical exercises with the students in order to facilitate the mastering of the complex and extensive material. In building our strategy of training for pathophysiology, we use the experience of the medical schools in Bulgaria and all around the world and we have enriched it with our original new ideas and methods.

Methods

Our experience shows that more effective and detailed mastering of the material was observed when using a combination of different methods, which include both classical lectures, presentations of educational films that introduce the etiology and pathogenesis of some basic pathological process or disease (shock, myocardial infarction, etc.) and others which require the active participation of students - tests, research papers, problem cases discussions, seminars and colloquia on various sections of the material and last, but not least – the practical work during the exercises.

Tests showed the best results when conducted on computer by each student individually. The test is carried out during the first 10 - 15 minutes of each practical exercise to check the preparation for the topic, which is announced in the curriculum for the semester. The computer program allows control and assessment of knowledge and verification of the correct answer. The exam at the end of the training course must include a summary computer test on all material with any combination of questions from each section, different for each student. We believe that conducting tests this way (by stages and summarized at the end) gives an objective idea of the overall preparation of students. Similar methods are used in many other medical schools (Ram Felix, 2008; Mufson et al., 2004).

Other method of theoretical training for students is preparing research papers on a theme chosen by individual students, which requires extracting significantly more expanded information (books, monographs, scientific journals), then presenting to the group and discussing with the active participation of the professor. Our experience shows that this is a very interesting and preferred by the students method.

Results

Discussing problem cases during the practical exercises is received with great interest, since this is a real bridge between the clinic and premedical disciplines. The problem case represents a pathology case with specific group of symptoms. Students are preparing basic comment upon the mechanisms of the development of symptoms that led them to suspected diagnosis. This method is widely used in various medical schools in the world, proved its effectiveness and is received with great interest by the students.

Further enrichment of the training is done through presentations of educational films during the lectures and exercises, which present fundamental questions of the theory of pathophysiology as well as specific pathological processes, surgery methods and mechanisms of the origin of pathological processes (acute respiratory failure, anaphylactic shock, myocardial infarction, etc.). Some of the subjects of practical exercises allow for individual work of each student on experimental animals for a demonstration of a pathological process, where experiments are conducted in full compliance with the law and lead to the acquisition of some practical skills that are essential to students during next stages of training (venous injection, punctions, etc.). At the end of the course during extracurricular time, pathophysiology evening is carried out when questions about the material are asked in the form of quizzes, games and competitions between the teams, thus a mood of fun and diversity is achieved as an added benefit. The quiz methods in pathophysiology education are useful and are practiced in other medical schools in the world (Lanou, 2008).
Conclusions and Implications

We can summarize the following: the mastering of a very serious matter such as the medical discipline of pathophysiology is vastly assisted and facilitated by the inclusion of different forms of presentation of the material, which require the participation of each student to a large extent. Our findings are confirmed and implemented at the end of each academic year by an inquiry among the medical students.

Acknowledgements

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THOUGHT EXPERIMENTS: A TOOL FOR TEACHING PHYSICS THEORIES IN SECONDARY EDUCATION
THE CASE OF “HEISENBERG’S MICROSCOPE”.1

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Abstract

This research was designed to investigate whether the Thought Experiment (TE) “Heisenberg’s Microscope”, as it has been transformed by Gamow in his popular book “Mr. Tompkins in Paperback”, can be used effectively in the teaching of the “uncertainty principle” to upper secondary school students. The sample of the research was 40 Greek students, in 11 groups of 3 to 4 students each. The findings of this research reveal that students, helped by the TE, were able (i) to derive a formula of the uncertainty principle, (ii) to explain that this principle is a general principle in nature and it is not a result of incompleteness of the experimental devices and (iii) to argue that it is impossible to determine the trajectory of a particle as a (geometrical) line. This suggests that the use of this TE has positive results in teaching the “uncertainty principle”.

Introduction

Thought Experiments (TEs) have played an important role in the development of physics and they continue to do so in modern physics (Reiner and Burko 2003). They help scientists to bridge the gap between empirical facts and theoretical concepts (Koyre 1968). Also, in the field of science teaching, teachers consider that TEs are indispensable tools when they have to teach physics laws that involve abstract and concise formulations. They feel that TEs narrow down the gap between the students’ everyday experience and the new concepts which have to be taught (Helm et al. 1985). This might suggest that TEs could also be proved to be useful tools in the teaching of quantum mechanics, the concepts of which are difficult to understand, not only by secondary education but also by the tertiary education students (Fischler and Lichtfeldt 1992, Johnston et. al 1998).

Moreover, a basic characteristic of TEs is that they include narrative (Nersessian 1993, Klassen 2006). This characteristic renders TEs a dynamic tool in the communication of scientists, not only among themselves, but also with the public. For example, Einstein (1917/1961) designed TEs not only for the development of his theories but also for their popularization. Einstein’s example was followed also by well known scientists, such as Gamow (1990) and Landau (1960), who wrote books for the popularization of physics theories. In these books a lot of TEs can be found, especially when the authors present physics theories of the 20th century (Velentzas et. al. 2005). Research shows that the code of science popularization (which is a non formal science code) appears to be very appealing to students (Halkia and Mantzouridis 2005).

Thus, in this work an attempt is made to teach the uncertainty principle (in the field of quantum mechanics) to upper secondary education students, by using a TE (“Heisenberg’s microscope”) in a popularized version.

1 The research has been funded by the University of Athens
The research question

A research has been designed to investigate whether the TE known as "Heisenberg's Microscope" (Heisenberg 1930/1949), in its popularized version by Gamow (1990), can be used effectively in the teaching of the "uncertainty principle" to students of secondary education. The main research question of this work is: To what extent does the use of the TE “Heisenberg’s microscope” help students of the upper secondary school to understand the “uncertainty principle” (to derive and apply the specific formula, to explain the meaning and realize the main consequences of the principle)?

Mode of inquiry

The study of the relevant literature, the results of the pilot research and a selection of passages from Gamow’s popular book “Mr. Tompkins in Paperback”, were used to design a lesson plan for the teaching of the uncertainty principle.

The lesson plan was carried out through semi-structured interviews in which the teacher acted both as an interviewer and as teacher, according to the “teaching experiment” method (Komorek & Duit 2004).

The main steps of each interview/implementation were:

1. The meaning of measurement in the context of classical physics.
2. The concept of the trajectory in the context of classical physics – “Performance” of the relevant TE.
3. “Performance” of the TE for the determination of a particle’s trajectory by taking into consideration quantum limitations - Formulation of the uncertainty principle.

The sample of the research was 40 upper secondary school students (aged 16, grade 11) from 6 different schools in the area of Athens. The students were divided into 11 groups of 3-4 students each.

The experimental implementation lasted 90 minutes for each group of students.

The data were collected by taping and transcribing the interviews (Fischler 2005), and by distributing a questionnaire to the students 15 days later.

To analyze the data methods of qualitative content analysis were applied (Erickson 1998).

Results

The TE “Heisenberg’s microscope” helped students to grasp the “uncertainty principle”.

Most of the students, having “performed” the specific TE (i.e. having followed the chain of syllogisms suggested by it), were able to:

- derive the formula of the uncertainty principle and answer correctly questions related to this formula. For example, students, making use of the knowledge gained by the TE, were able to differentiate between “the determination of the position or the speed…” and “the determination of the position and the speed simultaneously…”


- conclude that the uncertainty principle is a general principle in nature and not a result of incompleteness of the experimental devices. They justified their view, using the arguments presented in the TE, i.e. they assumed that the camera (in Gamow’s version of the TE) could detect only one photon with any wavelength.

- argue (contrary to their initial view) that it is impossible to determine the trajectory of a particle as a (geometrical) line. However, a number of students (about half of them) still had the idea that such a trajectory “exists”, but because of the uncertainty principle it is impossible to determine it. A number of students referred to the orbits of the electrons in the planetary model of the atom to support their view. This is maybe an indication that the instruction of quantum mechanics concepts to students of the upper secondary education demands a new physics teaching approach in secondary education in general (Hadzidaki 2008).

- apply the formula of the “uncertainty principle” in several cases of the macrocosm and the microcosm and they were led to the conclusion that its results are obvious in the microcosm.

The popularized version of the TE seems to be effective in the teaching of the “uncertainty principle”.

The way Gamow transformed the TE “Heisenberg’s microscope” to address the public, proved effective in the teaching of the uncertainty principle. The popularization code used by Gamow helped students to follow easily the text and focus on the physical meaning of the principle. Moreover, it kept students’ interest alive during the implementation. In particular, the TE “Heisenberg’s microscope”, as is presented by Gamow, proved effective for students in overcoming the difficulties met when trying to approach the “uncertainty principle”:

(i) As the pilot study showed, students had the view that an instrument of measurement does not affect the system that is under measurement. This would create a barrier when trying to approach the “uncertainty principle”. For this reason, questions based on Gamow’s text had been designed for the main implementation. Specifically, students were asked to compare the accuracy of the measurements of the temperature of an amount of water by thermometers of several sizes. The followed discussion in order to answer these questions helped students to overcome the barrier.

(ii) One crucial point for the development of the lesson plan is that students had to approach the idea that an increase of the wavelength causes an increase of the uncertainty in the position of an electron. But, students had not been taught anything before about the "resolving power". The use of Gamow’s popularization techniques (e.g. the analogies he used) helped students to overcome this difficulty. Thus, students having read the corresponding Gamow’s text were able to conclude that “we cannot observe details less than a wavelength” and they were able to choose between two values of wavelength in order to experimentally determine with higher precision (a) the momentum and (b) the position of a particle.

Conclusions and Implications

In this work a “historical” TE, as it was transformed for the public by a distinguished scientist, was utilized in teaching physics. Students, helped by this TE, grasped a part of scientific knowledge and managed to mentally approach situations beyond their every day experiences. Specifically, this research shows that the use of the TE “Heisenberg’s microscope”, as it was transformed in a popularized version by Gamow, has positive results in teaching the uncertainty principle to upper secondary school students. The investigation of the effectiveness of other TEs would help in reaching a general conclusion with regard to the value of TEs as educational tools for the teaching of physics theories with a high level of abstraction to upper secondary school students.
References


CHEMISTRY-SPECIFIC CHARACTERISTICS OF QUALITY

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Abstract

As a result of the international large-scale assessments TIMSS and PISA, the discussion about the quality of education, especially in science education, is pushed into the centre of attention. Many different characteristics influencing the learning process of individuals have been identified during the education research of quality so far, but most characteristics of quality in education are not for a specific subject. The aim of the study is to identify those chemistry-specific characteristics which enhance interest and have a positive effect on achievement in chemistry education. This will be achieved by observational research (video-analysis) with a system of categories. The importance of the identified characteristics will be verified by an intervention. Results of this study may offer practical instructions for phases of experiments in chemistry education to improve the learning process of the students.

Introduction

Models of quality in education

The term “quality” stands for condition and property. If one speaks about quality in education, the question arises, what “good education” is or which characteristics play a decisive role in it. Einsiedler (2002) defines quality in education as “a bundle of characteristics, which affects as a ‘condition side’ (process quality) teaching purposes and education purposes (product quality) positively.” Thus, ‘good education’ can be defined as something from which we can measure positive effects concerning the output of the students. Helmke (2003) describes factors of quality in education in an “offer and use model” (fig. 1). In this model, education shall be deemed to be an offer, whose effectiveness depends on the teacher, the context and the activity of learning (the use). In turn, the use depends on many mediators like the family, the achievement potential and the context.

Based on the offer and use model, Reusser and Pauli (2003) describe the quality of education in a systemic model (fig. 2). The systemic model of quality in education is divided into three levels: the system, the school and family, and class and individuals. All of these levels are subdivided into the quality of learning opportunity and the quality of using the offer, so they are all interacting. In my project, I will look at the class/individual level and within this level at the education, the characteristics of the students and the effects of education (output).

Subject-specific characteristics of quality in chemistry education

Many different characteristics that influence the learning process of individuals have been identified during the quality of education research so far (e.g.: Brophy & Good, 1986; Ditton, 2000; Helmke, 2003; Mayer, 2004). But most characteristics of quality in education are not for a specific subject. Helmke (2002) and Ditton (2002) state that it is “out of date” to look only at the general quality of education, so they call for specific characteristics of quality in specific subjects. The aim of the study is to identify those specific characteristics as per particulars given below.
As a result of the international large-scale assessments TIMSS/II (Baumert, Lehrmann, Lehrke, 1997) and PISA 2003 (Baumert, Prenzel, Blum, et al., 2005), the discussion about the quality of education, especially in science education has been pushed in the centre of attention. The immediate consequence was the increasing focus on measurable outputs or outcomes of education and no longer on the inputs. General educational standards have been established in Germany as a further result of the international large-scale assessments (KMK, 2004). These standards focus not only on content knowledge, but also on specific methods and procedures. The general educational standards describe the expected outputs of the students. For example:

- “Students conduct experiments and make investigations and record them.”
- “Students observe and describe phenomena and procedures and differentiate between observation and explication.”

Both points focus on experimental methods, and therefore I am focusing on experimental phases in chemistry education as a subject-specific criterion.
Gathering characteristics of quality in education

The international large-scale assessments have provided important information about the quality of the effect of education but not about the causes. For this reason, Helmke and Schrader (2007) ask for empirical education research, which complements the large-scale assessments. They believe that the aspects of the process of education have to be linked to the output of education.

To detect characteristics of quality in education, there are different methods. To collect events in a specific period of time, one can use low-inference rating (e.g. form of organisation). High-inference rating is an estimation procedure, so events are evaluated subjectively (e.g. the teacher’s questions are ambitious). If one wants to decide between the high- and low-inference ratings, there is an “accord-significance-dilemma” (Clausen, 2002). This means that the low-inference evaluation is more objective and reliable than the high-inference rating, but the high-inference rating shows more coherence to successful education.

If only questionnaires and interviews are used, you can only analyse the result of the lessons. By adding video analysis to these research methods, we can analyse the process of the lessons more completely. Since the video equipment is both affordable and precise, it becomes increasingly popular. To observe the education activities with video recordings has many key benefits: you can reanalyse them as often as required, the recording and analysing are temporally independent, non-verbal features like facial expressions or gestures can be recorded and analysed and digital videos can be analysed by software (e.g.: catmovie4 or videograph).

Research Questions

Based on the theoretical background the aim of my project is to translate the results of the general quality research into specific characteristics in chemistry education (in particular the experimental phases) to identify chemistry-specific characteristics of quality that enhance the learning process. This will be achieved by observational research (video-analysis) with a system of categories.

The following research questions arise from the objectives:

- Which general characteristics can be transferred to experimental phases in chemistry education?
- Which requirement of intervention can be derived from observed chemistry education?
- What effect does the intervention have on the output, interest and motivation of the students?

Methods

Procedure

In the school year 2008/2009 18 different lessons in chemistry education were videotaped. The topic was alcohol in the 10th grade of secondary schools (mid-level1). The teachers (N = 16) were instructed to demonstrate a typical chemistry lesson under the condition that at least one experiment should be conducted. These 18 classes are the first control-group. One year later (school year 2009/2010), at least 10 of the 16 teachers2 will be consulted for

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1 In Germany, the education system is divided into three school types, which differentiate between a low (“Hauptschule”), a mid (“Realschule”) and a high (“Gymnasium”) teaching level. The topic was chosen on the basis of the national curricula of North-rheine-Westfalia.

2 We assume, that approximately ⅓ of the teachers will drop out for various reasons (e.g. they do not teach a 10th grade class any longer)
an intervention in which the characteristics of quality in experimental phases will be given. The direct control-group will be the parallel classes (without intervention), which will be videotaped previous to the intervention-group.

Video analysis

In order to analyse the videos, especially the experimental phases, a high- and low-inferent category system was constructed. This category system (fig. 3) detects characteristics of education, which are determinants with an effect for education-goals and characteristics of students. It is based on the systemic model of quality in education (Reusser & Pauli, 2003), the offer and use model (Helmke, 2003) and results of the general quality of education research (Biggs, 1979; Ditton, 2000; Haenisch, 1999; Harvey & Green, 1993; Smith, 1985; Tobin & Fraser, 2003).

Figure 3. Category system

The surface structure of the lessons (low-inferent) will be analysed by a time sampling (10 second steps) with the program Videograph®. The inter-rater reliability of the ratings can be calculated by cross-tabs (Cohen's Kappa).

The deep structure of a lesson will be rated by a rating-questionnaire with a four-point Likert-Scale (strongly agree – strongly disagree). The basis for the raters is a coding-manual in which every item is defined with given examples. During the training period of the high-inferent category system, it has been shown that it was very

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3 This control-group is to control if there are the time-based variances or changes in the school (e.g. a new book, new chemistry rooms)
difficult to make a decision over the entire term of the lesson. So we decided to divide the category system into three parts:

1. Pre-processing of the experiment
2. Performance of the experiment
3. Post-processing of the experiment

Every part of the high-inferent category system has the same categories, with varying some subcategories. The inter-rater reliability of the ratings can be calculated by the intraclass coefficient (ICC).

Paper-Pencil-Tests

To be able to explain chemistry education and not only to describe it, video-analysis should be completed using by further criteria like interest, motivation, intelligence or capacity (Seidel et al., 2006). Many variables of the tests are influenced by individual ability or intelligence. To consider this, the cognitive ability test (Heller & Perleth, 2000) will be employed, so the test data can be implicated and analysed more precisely. An achievement test (pre-post design) can be used to control the students’ development of performance. This test will collect the pre-knowledge about the topic alcohol and the knowledge after the videotaped education. Additionally, a test on scientific procedures (Klos, S.; Henke, C.; Kieren; C.; Walpuski, M.; Sumfleth, E., 2008) will be used. This test engages the “know-how” about the scientific mode of operation. Therein, different cognitive levels are included. To interpret the variables, the chemistry-specific interest and motivation will be collected (pre-post), which influence the activity of learning. After the videotaped lessons, a feedback questionnaire for students will be used. This questionnaire allows visiting the education from another point of view: the target group. In the most cases, students are acquainted with the teacher, so they can estimate the education over a longer period than the video-rater.

Design in summary

![Design of the study](image)

Figure 4. Design of the study
First Results

Inter-rater reliability

The first step to test the category system is to train the observers with available video data. The results (inter-rater reliability) of this pilot study were satisfying to very good. After the training, the observers rated the 18 videos from school year 2008/2009. The following table shows the inter-rater reliability of the category system:

### Table 1. Inter-rater reliability of the category system

<table>
<thead>
<tr>
<th>Category</th>
<th>Inter-rater reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of the lesson</td>
<td>K = .91 – 1.0</td>
</tr>
<tr>
<td>Portion of communication</td>
<td>K = .55 – .99</td>
</tr>
<tr>
<td>Contents of communication</td>
<td>K = .62 – 1.0</td>
</tr>
<tr>
<td>Organisation</td>
<td>K = .82 – 1.0</td>
</tr>
<tr>
<td>Experimental phases</td>
<td>K = .89 – 1.0</td>
</tr>
<tr>
<td>Number of experiments</td>
<td>K = .78 – 1.0</td>
</tr>
<tr>
<td>Repeated experiments</td>
<td>K = .72 – 1.0</td>
</tr>
<tr>
<td>Organisation in experimental phases</td>
<td>K = .91 – 1.0</td>
</tr>
<tr>
<td>Distribution of work</td>
<td>K = .81 – 1.0</td>
</tr>
<tr>
<td>Procedure</td>
<td>K = .73 – 1.0</td>
</tr>
<tr>
<td>Equipment</td>
<td>K = .73 – 1.0</td>
</tr>
<tr>
<td>Function</td>
<td>K = .81 – 1.0</td>
</tr>
<tr>
<td>Way of securing results</td>
<td>K = .73 – 1.0</td>
</tr>
<tr>
<td>Instruction-efficiency</td>
<td>ICCunjust = 0.87 (F(1,113)=24.81; p ≤ 0.001)</td>
</tr>
<tr>
<td>Clarity and structuredness</td>
<td>ICCunjust = 0.87 (F(1,58)=22.90; p ≤ 0.001)</td>
</tr>
<tr>
<td>Openness</td>
<td>ICCunjust = 0.87 (F(1,40)=28.74; p ≤ 0.001)</td>
</tr>
<tr>
<td>Problem solving</td>
<td>ICCunjust = 0.86 (F(1,11)=30.32; p ≤ 0.001)</td>
</tr>
<tr>
<td>Student orientation</td>
<td>ICCunjust = 0.82 (F(1,25)=23.47; p ≤ 0.001)</td>
</tr>
<tr>
<td>Security</td>
<td>ICCunjust = 0.85 (F(1,56)=28.71; p ≤ 0.001)</td>
</tr>
<tr>
<td>Success of the experiment</td>
<td>ICCunjust = 0.92 (F(1,11)=39.62; p ≤ 0.001)</td>
</tr>
</tbody>
</table>

Based on the score, extreme-groups were formed to validate the high-inferential category system (fig. 5). It could be shown, that the difference of the learning achievement is highly significant (F(1,132) = 17.58; p ≤ 0.001; partial eta² = .118). Additionally, some of the high-inferential items were used as feedback questionnaire for the students. The inter-rater reliability between the raters and the students feedback is also highly significant (ICCunjust=0.39 (F(1,40)=2,29; p ≤ 0.001)).
Figure 5. Learning achievement of the extreme-groups

Descriptive results

It could be observed that the planning of the experiments averages 15.7% of the teaching time, the procedure 57.9% and the analysis 18.6%. Thus, 92.2% of the teaching time is used for experimentation. This is not surprising because the condition was that the teachers had to conduct at least one experiment. Mostly, the procedure of the experiments is organized in group work (93.6%). In certain cases, the students have to work at different stations (2.3%) or have to conduct a demonstration-experiment (4.1%). They spend more time to conduct the same experiment (92.0%) compared to conducting different experiments. Furthermore, it could be observed that the experiments are mostly used at the beginning of the lessons (61.0%). Conducting an experiment to test a hypothesis is seen in 27.0% of the videos. The third function of an experiment, which could be observed, is confirming a hypothesis (12.0%).

Discussion and conclusions

The results of the inter-rater reliability of the low-inferent ratings are between $0.55 \leq k \leq 1.0$, so the closeness of agreement of the category system (surface structure) is satisfying up to very good (Wirtz & Caspar, 2002). The worst results of $k$ are the categories “contents of communication” and “portion of communication”. The cause for these (only satisfying) results is that the rating is time-based and not event-based. So we will rate these categories by events (change of speaking) to increase the reliability.

Also the closeness of agreement of the high-inferent ratings could be shown: all the inter-rater reliabilities are highly significant ($p \leq 0.001$). Additionally the validity of the category system is verified by the student ratings and the high significant difference of the learning achievement between the extreme-groups.

References


Approaching Problem Solving Steps with Regard to Task Analysis

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Abstract

The aim of this study is to approach the ways to solve a problem with regard to task analysis and to contribute to the solving process. Problem solving is a frequently addressed method; and, several approaches have been developed which are directed towards improving and applying this method. When the importance of going through the process rather than achieving a result in problem solving is taken into consideration, the necessity of these kinds of studies becomes obvious. Polya’s problem solving approach is one of them. Task analysis is used to define the tasks that are necessary to realize a certain end according to certain steps. In this study, problem solving stages determined by Polya are approached within the context of task analysis, and, a hierarchical task alignment is done between each step and their sub-steps. With this alignment, it is expected that students should be able to predict the procedures in the problem solving process, and, with the feedbacks achieved after this process, that they should have the ability to see if they have achieved the end or not.

Introduction

Problem solving is a concept that is frequently encountered in the education process, and it increasingly gains importance. The aim of problem solving should be accommodating the person with enough acquisition within the problem solving process rather than merely solving the problem. In the process of problem solving, the person is in a position to decide what the most rational problem solving method is and how he or she should act. Any indecision experienced in this stage may cause a weakening in the person’s problem solving skills. On the other hand, solving the daily problems efficiently helps the person strengthen himself or herself by using his/her skills to deal with difficulties, and maintain the harmony in a balanced way (Sardogan et al, 2006). One specific area of problem solving is solving mathematical problems. Mathematical problem solving is analyzed by Kienel (1977) under five categories. The 1st type of problems can be solved by applying a rule, an algorithm, or a procedure. In the 1st type of problems, the rule, the algorithm, or the procedure is clearly stated. In the 2nd type of problems, the rule, the algorithm, or the procedure is known by the problem solver yet is not clearly stated. The 3rd type of problems is formed by way of combining the rules, the algorithms, or the procedures known by the problem solver. The 1st and the 3rd type of problems can be solved by applying a rule, an algorithm, or a procedure. The 4th types of problems are orally called “problems that are encountered in everyday life.” In the 4th type of problems, first of all the mathematical content should be solved, and the 4th type of problems should be transformed into a mathematical problem in order to get a 1st or 3rd type of problem. The 5th type of problems consists of all other types of problems. In order to achieve the solution of a 5th type of problem, the knowledge of the rules, the algorithms, or the procedures are not in itself enough (Gür & Kandemir, 2006).

When it comes to the task analysis, it is a method used to define the tasks according to specific steps. A task analysis should provide a framework within which various approaches to design can be understood (Chandrasekara, 1990). Gürol (2002) defines task analysis as determining the expectations of those who do the application after having been taught it. According to Gürol (2002), after determining the tasks and prerequisites, it is necessary to
analyze the learned things. In this field, in addition to Gagne Model which is based on the hierarchical order of the task analysis and the tasks, different programmed teaching theories have been developed such as Pressley’s approach which bases itself on the control and reinforcement of knowledge, which has been displayed by various methods, through multiple choice questions; Skinner’s direct programming, and Crowder’s branching technique (Özbek, 2005). It is possible to come across with task analysis application in various different fields. Hackos and Redish (1998), who work in the field of computer applications, define task analysis focusing on the following questions (Coskunserce & Dursun, 2008):

- What are the goals of the users; what do they try to achieve?
- What do they do to achieve these goals?
- What are the personal, social and cultural characteristics of the users?
- How are the users influenced by their physical environment?
- How do the past knowledge and experience of the users influence their approach in realizing the tasks and their ideas about their work?

In their study, Coskunserce and Dursun (2008) mention the following information about task analysis: When task analysis is done, first of all, the task to be analyzed should be determined. The determined task, then, should be divided into four-eight sub-tasks. The sub-tasks should be written down as goals, and they should cover the whole of the analyzed subject. The sub-tasks should be drawn in the form of a diagram and one must make sure that they cover the whole task. To what extent the details will be shown should also be determined. The details should be shown on the diagram by way of enumeration. Then, one should ask the opinion of a person, who has not been included in the solving process, yet who is learned in the subject and the tasks, on the sustainability of the solution. Lastly, the person who analyzes the tasks should find new tasks that support the new methods and goals to make the tasks more effective.

A task structure is a description of the task, proposed methods for it, the internal and external subtasks, knowledge required for the methods, and any control strategies for the method. Thus, the task analysis provides a clear road map for knowledge acquisition. One way to conduct a task analysis is to develop a task structure (Chandrasekaran, 1989) that lays out the relation between a task, applicable methods for it, the knowledge requirements for the methods, and the subtasks set up by them (Chandrasekara, 1990).

We can show the essential questions that we will take into consideration in the realization of the task analysis process in a scheme as follows:

![Figure 1. Task Analysis Process](image-url)
In this study, making an analysis of the tasks that will be encountered in the problem solving process and making the problem solving clear for students by providing this process in a task alignment are aimed. To this end, in the approaches to problem solving, Polya’s Problem Solving Approach is used, and a logical alignment is made, which is the base of the task analysis of the steps here. As is known, Polya gathers his heuristic approach under four main headings. These are also known as problem solving steps. These steps are:

1. Understanding the problem

2. Making a plan for the solution
   - Making a systematic list
   - Prediction – control
   - Drawing Diagram
   - Finding a correlation
   - Prediction

3. Application of the made plan

4. Evaluation

The task analysis of the problem solving steps here is given in Figure-2. In this scheme, problem solving main task, Polya’s each problem solving step, sub-tasks belonging to this task, and sub-tasks belonging to these sub-tasks are defined.

In accordance with the information provided in this scheme, a task analysis flow scheme which the students are recommended to follow during the problem solving process is prepared (Figure 3). In this scheme, the meanings of the boxes used are as follows (Cabr, 2007):

- : for input-output points
- : for studies where there are some mental/physical operations
- : for decisions and points where there is one of the many operations
Problems solving

1. Understanding the problem
   1.1. Restating the problem in one’s own words
   1.2. Restating the problem in one’s own figures and
       1.3. Restating the problem in a way that is clear to others

2. Preparing a plan for the solution
   2.1. Making a systematic list
       2.1.1. List the givens
       2.1.2. List the requirements

2.2. Prediction-control
    2.2.1. The correlation to be applied is
    2.3. Drawing a diagram
       2.3.1. Design auxiliary tables and graphics

2.4. Finding a correlation
    2.4.1. Determining the formulas and algorithms to be applied.
    2.5. Prediction

3. Application of the made plan
   3.1. Correlation, formula, or algorithm are tried.
   3.2. Observe and try to reach the solution

4. Evaluation
   4.1. An evaluation of the made plan is done. The way of solving is revised
   4.2. A new plan is made
   4.3. Can it be tried in any other way. Revise
   Work out the way of solution
Problem State

List of givens and requirements

Determining the relation to be applied.

Drawing auxiliary tables/graphics

Determining the formulas and algorithms to be applied

Preparing a plan for the solution

Application of the plan

Evaluation of the solution way

Can it be tried in any other ways?

Yes

Work out the way of solution

Yes

Exit

No

Make a new plan

No

Figure 3. An Application of Task Analysis to Problem Solving Steps.
Conclusions and Implications

To make an analysis of the tasks that one may come across with during problem solving and to provide a task list for this process makes problem solving more comprehensible for students. Especially in the face of situations that are complex and inclusive of several sub-problems, task analysis method can be used to help solve the problem in an organized way. Sometimes, we may have to use problem solving strategies scientific research that is extensive in nature and the solution of which necessitates a long time. In such cases, it is rather important to plan all sorts of activities, to apply and evaluate them in the given time. With task analysis technique, the student is able to see what he has done in each of the steps of problem solving and what he has to do on the control diagram. If there is a mistake or deficit in one of the task diagrams, one can easily and without wasting any time go back on the diagram and make the necessary corrections. In short, we can say that making a cycle of the problem solving process by way of a task analysis enables the student to have feedback during the problem solving process so that he can start all over or follow his steps backwards to identify the point where he has a problem. Hence, this means a more organized use of time in scientific research.

In further stages, the proficiency of this scheme can be proven by way of applying it to various problems and if there are any deficiencies these may be detected so that it can be improved.

Although there are several approaches to problem solving steps, giving these approaches in an outline may cause students to be deprived of detailed information and guidance in the process. The main aim in this study is to provide a step to eliminate this deficiency. Turning the problem solving process a cycle with the help of task analysis, because it provides feedback for the student in the end, will either make the student restart the process or to follow back the steps so that he or she can identify the problematic point. In the following phases, by way of applying this scheme to various problems, its proficiency may be proven, or, should there be any deficiencies, they may be determined and under the light of suggestions, the scheme may be improved.

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TENDENCIES AND CONTRIBUTIONS OF SCIENCE TEXTBOOKS RESEARCH

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Abstract

The number of studies on science textbooks has grown in different parts of the world, and it reveals the importance of this tool on science teaching. Brazilian research on science textbooks demonstrate that the majority of studies are concentrated on content studies, with a focus on science conceptual errors (misconceptions), ideological aspects of the science content, and images of science. In this paper we aimed at investigating the current international tendency of science textbook research. We analyzed (N=77) papers from 29 countries from the proceedings of the International Meeting “Critical Analysis of school science textbook” happened in 2007. We analyzed each paper’s focus, the type of research methodology used, the number of researchers involved, the area of study, the focus of the topic being investigated, the educational level of the study, and the nationality of the research. Data showed that the majority of the studies (approximately 88%) had a focus on the science contents of the textbook. These studies were more concentrated on the subject of Biology (nearly 42.3%), and centralized on secondary level education. The researchers used, principally, qualitative methodologies, and the majority of papers came mainly from France, Tunisia, and Brazil.

Introduction

In the last two decades, research has grown, nationally and internationally, with respect to investigations on science textbooks and its relevance on science teaching. Recently, an International Meeting took place in Tunisia (2007) “Critical Analysis of school science textbook” promoted by the International Organization for Science and Technology Education (IOSTE). This meeting gathered researchers from 29 countries, and it shows us the importance of textbook on the teaching context.

In the European context, a research project was presented: Biohead-Citizen “Biology, Health and Environmental Education for better Citizenship” (FP6) is other example of science textbook’ relevance. The project works on a comparative analysis of textbooks contents from 19 various countries.

In many parts of the world, textbooks have been analyzed. For example, in the United States, Hubisz (2003) evaluated Physics’ textbook used in elementary school and identified, among other things, conceptual mistakes, unsuitable illustrations, inadequate discussion for the target students age range, and in some editions no experimental activities. In the European context, Knain (2001) performed a study with Norwegian textbook and revealed that ideological aspects would need more careful consideration, as he found out that the image of the nature of science described to students shows scientists individually “discovering” the truth through experiments. Also in Europe, some of the most investigated aspects of textbooks are the approaches to some Biology core concepts, which may provide information regarding the types of interactions between scientific knowledge, social practices, and value systems (Bernard & Clément, 2005); the didactic obstacles that may arise among students due to the maintenance of traditional focus (Clément, 2005); or the generation of that same kind of obstacle due to the use of mistaken images (Carvalho, Silva, Clément, & 2005). In South America, Niaz et. al. (2002) in Venezuela, understood that the traditional approach for Chemistry textbook highlights experimental details while disregards the
way science is made, for not including its historical and philosophical perspective, an aspect that would make science learning more significant for the students.

In Brazil, studies have revealed that the textbook plays a fundamental role in science teaching and learning in schools, and is the most used resource in science teaching (Batista, 2002; Carneiro, Santos e Mól, 2005). Nevertheless, there are fewer studies investigating teachers’ criteria for choosing science textbooks in Brazilian public schools (Bizzo et al., 2007), or evaluating Brazilian high school biology textbooks in order to produce a guide to orientate the choice of textbooks to be bought by the government (El-Hani, Roque, & Rocha, 2006).

Some studies in the Brazilian context have demonstrated that the majority of research is concentrated on science content in textbooks, focusing on conceptual errors, ideological aspects, image of science (e.g., Cassab, 2003). An historical account on the issue of objective and subjective factors in Brazilian science textbooks assessment shows that publishers traditionally do not accept arguments based on ideological assumptions, and many cases went to court, arguing that assessments were a sort of censorship. The Brazilian Federal Court decided that assessments based on content accuracy could not be considered censorship (Bizzo, 2002).

Nevertheless, there are few studies focusing on other aspects of science textbook development and usage including: authors, editors, costs, finances, and the role of teachers and students. This means that there is a narrow understanding of all the elements involved in science textbook development. This lack of research could be to some extent an obstacle because if we know more about all aspects new ideas and innovations on science teaching and students learning could be put forward.

In this paper we focus upon the current international tendency of science textbook research. We analyzed 77 papers from 29 countries presented on the International Meeting “Critical Analysis of school science textbook”. The overall research question being addressed in this study is: What is the current international tendency of science textbook research? To address this question, data were collected from the proceedings of International Meeting “Critical Analysis of school science textbook” promoted by IOSTE in Tunisia (February/2007).

**Methods**

From all papers presented in the meeting 77 papers from 29 countries were selected using two criteria: paper should be related to the traditional science disciplines (Biology, Chemistry and Physics), and linked with primary or secondary education.

The paper analysis started with a global and generalized reading, from which four definitive categories emerged, and then a grid of analysis was constructed in order to facilitate the analysis.

The categories focused on:

1. Authors and editors; this group was divided into two sub-categories: (a) criteria for the conceptual content choosing, and (b) criteria for the illustration choosing.

2. Teachers as users, this group was divided into two sub-categories as well: (a) the process of choice of textbooks, and (b) the ways textbooks were used in classrooms.

3. Students as users; this group was also divided like the above categories: (a) the ways textbooks are used, and (b) students’ outputs after book-based learning.

4. Textbook content; this group was divided into five sub-categories: (a) conceptual contents, here were grouped the papers that investigated the concepts presentation, the concepts organization, conceptual mistakes, didactic transposition, and structure, syntax and language; (b) ideology; (c) image of science; (d) illustrations; and (e) educational conception.

One paper could bring more than one aspect studied, and therefore could be involved in different categories; this explains the difference between total number of papers (n=77) and studies considered (n=140).
We also analyzed, in all papers, the type of methodology used, the number of researchers involved, the subject area of study, and the main science topic studied, the educational level which the study was situated, and the nationality of the research.

Results

Results are presented according to the previously defined categories and are summarized in Table 1:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Sub-categories</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Authors and editors</td>
<td>criteria for the choice of conceptual contents</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td>criteria for the production illustrations</td>
<td>01</td>
</tr>
<tr>
<td>2 Teachers as users</td>
<td>the process of choice of textbooks</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>the ways textbooks were used in classrooms.</td>
<td>07</td>
</tr>
<tr>
<td>3 Students as user</td>
<td>the uses of textbook</td>
<td>02</td>
</tr>
<tr>
<td></td>
<td>the student’ learning</td>
<td>04</td>
</tr>
<tr>
<td>4 Textbook content</td>
<td>conceptual contents</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>ideology and values</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Image of science</td>
<td>02</td>
</tr>
<tr>
<td></td>
<td>Illustrations and images</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Educational conception</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>140</td>
</tr>
</tbody>
</table>

There were few studies focusing on the categories 1 “Authors and editors”, and 3 “Students as user”. There were also just 10 papers with the focus on teachers’ users. According to Carneiro, Santos e Mól (2005) despite existing a great number of studies investigating science textbook, the number of researches examining the teachers and students’ conception or the ways textbooks have been used are still inexpressive.

It is possible to see that the majority of the studies (approximately 88%) focused on science contents of the book (category 4). Within this category almost 48% studied the conceptual content, 27% investigated the illustrations and images, and 9% examined the educational conception of the science textbook.

In relation to the area of the study the papers were distributed as follows: 42,3% in Biology with the more studied topics being, among others, sex education, environmental education, and ecology; 15,5% in Physics exploring topics like energy; 6,9% in Chemistry examining topics such as gases and solutions, 12,7% in General Science.

As to educational level in which the study was involved 22,2% were centralized on elementary school level (students from 6-14), 57,2% on the high school (students from 15-18), and 20,1% in both.

The analysis of the methodological approach showed that 79,3% of the textbook studies were based on qualitative methods, 3,9% on quantitative, and 16,8% used both methodologies.

Finally, from the analysis of all the papers it was evident that the research from France represented almost 20% of the total studies presented at the meeting. Furthermore, nearly 19% of the studies came from Tunisia and 10% were from Brazil.
Conclusions and implications

Our results show that the international perspective on the issue of science textbook assessment relies heavily on the conceptual content, despite the fact that many other factors are considered relevant.

This result had also been found in Brazil and therefore it is not a local reality, on the contrary, there has been an international tendency to assess textbooks taking into account primarily their conceptual content.

Some researchers have argued, in the Brazilian context, that this is a poor perspective, which should leave space for other analyses, such as ideological perspectives on science issues etc (Carneiro, Santos e Mól 2005; Cassab, 2003).

Some authors state that assessing conceptual content would give us a narrow understanding of all the elements involved in science textbook development. The rationale for conceptual assessment has been the role of content and its accuracy in science education; however, there is a still a long way in which research could bring a deeper understanding of what has been considered an “accurate” approach to several concepts. The simple comparison with academic versions is not reasonable, as it does not considers didactic transposition procedures and outputs. Moreover, the complexity of other aspects of textbooks, related to variables linked to authors, editors, costs, users, etc, should also be addressed.

If a wider picture of this important educational tool is needed, it is necessary not only to enlarge the scope of the researches, investigating all aspects of science textbooks, but also to seek for a deeper understanding of what “correct” concepts are like.

It is important to overcome the common sense that it is easy to assess science textbooks, and that we already have all theoretical tools to carry on the task. Johnsen (1996) goes beyond this, and using a kaleidoscope analogy, suggests that textbook analysis must be more integrated and synchronized with all the chain parts that involves textbook elaboration, production, users, etc.

References


SMART USE OF COMPUTERS AND TECHNOLOGY AS A MEANS TO INTRODUCE INNOVATIVE EDUCATIONAL IDEAS TO SCIENCE CLASSROOMS

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General Abstract

The purpose of this joint article is to describe a variety of innovative possibilities to integrate technology and computers with pedagogy to achieve meaningful learning. All the papers deal with innovative uses of computers and technology for teaching scientific concepts, enhancing cognitive skills and constructing better classroom communication. Paper 1, "Animated Illustrations - Finding Critical Factors for An Effective Information Processing" (Girwidz, Lippstreu and Wintterlin), compares the use of animations with that of still pictures in the process of teaching physical concepts. The research investigates the combination with oral presentation and with written texts. It also relates to the influence of the various combinations on teaching students with various levels of academic achievements. Paper 2, "Science Classes with 1:1 Laptops and Virtual Learning Campus as a Routine: Diverse Methods of Instruction and Development of Scientific and Information Literacy among Students" (Spektor-Levy, Menashe, Gazit, and Raviv), relates to the use of personal laptop computers that were provided to students and teachers for school and home use (24/7). The ability of students to surf the Internet at any given moment can be an important factor in teaching them science. Papers 3 and 4 relate to the use of still pictures in a mediated way in constructing Thinking Journeys (TJ's) for teaching the day-night cycle concept. The study described in Paper 3, "Promoting Dialogic Discussions with a Technology-Based Pedagogy" (Weizman, Hyunju Lee, Feldman and Schur), relates to the use of CRS technology for constructing communication with classroom students. Paper 4, "Computerized use of Thinking Journey (TJ) mode of instruction as a means to overcome students' egocentricity and enhance their conceptual understanding of the day-night cycle" (Schur, Penso and Schwarz), relates to a computerized use of TJ interactions done in the classroom where communication was established between four students and a mediator with the use of Digalo.

General Introduction

"The least influential element on education is technology…There are many promises about the huge potential contribution of technology to education, but until now, almost forty years after the beginning of the technological era, the evidences of realizing this potential are very rare." (Salomon, 2008). The speaker is none other than Prof. Gabriel Salomon, of Haifa University, one of the leading proponents and contributors to technology and computers education in the last forty years in Israel and in many other countries. Salomon carries on: "In order for the
technology to contribute meaningfully to education one has to introduce very big changes in education." (Salomon, 2008). This means that one has to find connections between the use of technology and computers with some leading educational ideas. This is the purpose of this group of researches.

The four researches that construct this paper give several perspectives on the ways that computers and technology can be of substantial aid to the teachers in their everyday encounter with students in the science classrooms. The emphasis is not on the computers or the technology but on the way it can be used for teaching in regular classroom settings.
ANIMATED ILLUSTRATIONS - FINDING CRITICAL FACTORS FOR AN EFFECTIVE INFORMATION PROCESSING

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Introduction

Animations and visualizations are not isolated means for learning. How should additional information be designed? Our study focused on spoken or written text that gives hints for processing and / or explains further details. One challenging and probably a fruitful employment for illustrations and animations are phenomena that are not visible with naked eyes. These are characteristics for the kind of learning content regarded in this paper. The focus is laid on visuals that are used to explain how infrared motion detectors and infrared thermometers work. Illustrated graphs, animations and thermal imaging are employed and their information value will be discussed.

Rationale

The theoretical background is based on the work of Mayer (2001), Schnotz & Bannert (2003), Girwidz et al. (2006). Important design features for the used learning environment can shortly be described with the following key words: a) Multicodal learning: Especially animated visuals are used to illustrate physical concepts. b) Multimodal learning: Oral information is given to support processing of visual information. c) Techniques like the supplantation principle (Salomon, 1979) are used to explain and illustrate abstract concepts. Processes and procedures that learners cannot perform by their own are realized and shown by media, with the intention that they will be adopted. In this context, seeing connections between pictures, illustrations and diagrams is meant. d) Interactivity is implemented to enhance active learning. Navigation tools are provided to adapt the flow of information to the learners' abilities and to avoid cognitive overload. e) Illustrations are embedded into a track of information that builds up a knowledge structure and integrates it into a sense making context. The intention is also to work against inert knowledge.

The learning subjects in general deal with everyday physics - here with infrared motion detectors and infrared thermometers. General characteristics of the learning subjects are: a) Fundamental but complex concepts are examined (here infrared radiation). b) The topics are not visible in nature. Therefore imagination is important. c) Dynamic process components are essential.

Methods

This paper focuses on the multimodality aspect and the comparison between animations and still pictures. To find out more, four classes of 9th graders (together 99 students) were taught with four different program versions. Each class was divided into four subgroups, and they got learning programs with the following specifications: a) animations with additional aural information. b) animations with written information. c) still pictures and aural information. d) still pictures and written information.
Three subtests / questionnaires were applied: a) A knowledge test (also with tree subdivisions) was administered. Each of the three parts referred to knowledge that could only be drawn from a specific coding (5 questions only referred to illustrations; 5 questions only referred to text; 6 questions referred to combinations of text and visuals). b) Students assessed the visualizations, especially attractiveness and their benefits for learning. c) Students assessed the learning program. d) Differences in learning results and students’ assessments were examined with t-tests, and interferences tested with analysis of variance. Also correlations between different variables were analyzed.

Results

1. Students assessed the attractiveness and the value of illustrations and text. - Text was assessed not to be as good for learning as visual information. (The difference was highly significant). - The attractiveness of visuals was assessed to be very good (4.2 out of 5) and much higher than text information.

2. Animations compared to still pictures and explanatory text.
   An ANOVA analyses showed significant differences between subgroups that got:
   a) Animation with spoken explanations   b) still pictures with spoken explanations
   c) animations with written text          d) still pictures with written text.
   Animations with spoken text led to the best results. However this was the case only for visual based knowledge.

3. The next issue was whether spoken or written text was more effective. We found significant differences between visual based information and text based information: In combination with illustrations spoken text was more effective. For text based knowledge, however, more detailed inspection revealed that there is to distinguish between more capable and less capable students (see below).

4. Were there differences between types of learners? We asked the students whether they preferred aural or written information for learning. 35 percent preferred aural, 65 percent written text. However, we could not see significant differences in learning results if the students got their preferred mode.

5. Were there differences between high and low achievers? According to their prior school grades in science we distinguished higher and lower achievers, using a median split for statistics. There was a significant interaction effect between prior knowledge / initial abilities and modality of information: Low achieving students could profit from spoken text in combination with visual information. Regarding pure text information, spoken text was not so good for high achieving students. They performed better, when they could read text on their own. Concerning the use of spoken or written information in combination with text based knowledge we found: a) High achieving students could process better written text, which they could read by their own. b) For low achieving students, aural information was better (also) for understanding textual information.

6. The assessments of students and their learning results: We expected a correlation between the students' assessment of the learning material and their own test performance. However, this could only be found for text based knowledge. There was no correlation between the students' assessments of the material and their performance in the visual based knowledge test. Two possible reasons might be: a) A ceiling effect, because in the illustrations students got very good marks, in general. b) There is a lack of experience with illustration and students are not able to estimate the relevant factors correctly.
Conclusions and Implications

The study concentrated on process oriented phenomena that are not directly visible, and where imagination is important for understanding. For time dependent aspects animations appeared to be good for our students especially using the modality effect. The fact, that especially not so good students profited from spoken text can be seen in conformity with cognitive load theory. However, additional spoken text information is not always better. We suppose that this is because of a more longwinded access to repeat spoken information. As a consequence for the more capable students it is more convenient for them to process written text in the case that primarily text based information is relevant. Also reporting from better students confirms this hypothesis. At least the results showed that capabilities of students have to be taken into account. A last impression should also be mentioned: Visual information is more and more given in learning material. However, processing of visual information also has to be trained. We think that more research is necessary to clear up the best way to teach, also taking into account the capabilities of students.
SCIENCE CLASSES WITH 1:1 LAPTOPS AND VIRTUAL LEARNING CAMPUS AS A ROUTINE: DIVERSE METHODS OF INSTRUCTION AND DEVELOPMENT OF SCIENTIFIC AND INFORMATION LITERACY AMONG STUDENTS

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Dafna Raviv
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Introduction

In the last decades, reforms in science and technology education took place in many countries. These reforms formulated new standards and reflect the overall goal of preparing students for the requirements of the 21st century knowledge society. Educators are required to redefine educational goals and integrate technology into school curriculum in general, and science studies in particular. The integration of technology within schools has varied: From desk-top computers, to laptop computers (1:1); from computer use in a specific lesson, to computer use anytime anywhere (24/7), etc. This research describes an innovative educational project that started in 2006 in Israel, taking place in four schools (three elementary schools and one middle school) of two small urban communities (grades 5th – 9th). All students and all teachers were provided with personal laptop computers for class and home use. The teaching and learning is taking place as a routine in an ICT saturated environment and Virtual Learning Campus (VLC). Due to the expansion of such initiatives in many countries, it is required to question the effectiveness of such learning environments (Penuel, 2006; Kozma, 2003), to characterize the One-to-One learning environments and to analyze the impact of such environments on students’ achievements and other variables (Beresford-Hill, 2000).

Rationale

Decades ago, policy-makers hoped that the introduction of computers would lead directly to better instruction and better achievements. Nowadays, it is clear that simply providing computers to schools is not enough. At a minimum, learning goals, curricula, teaching strategies, and assessments must change as well (Zucker & Light, 2009). Thus, the aim of this study was to characterize the teaching and learning processes in science classes provided with personal laptop computers (1:1) and Virtual Learning Campus. The following research questions were addressed:

In science classes with 1:1 laptops and VLC:

- What are the characteristics of the instruction in regards to instructional strategies, lesson plan and visual representations?
- What are the characteristics of the learning in regards to the development of scientific literacy and information literacy?
Methods

In this paper we present data collected from 5th - 9th grades students and their teachers. Participants included 701 - Students: 50.7% boys, 49.3% girls and 50 Teachers.

The research data collected through standard qualitative (classroom observations, interviews, analysis of the virtual learning environments, students’ outcomes) and quantitative (pre-post questionnaires) methods.

Results

Main research findings:

1. Students reported on improvement in skills such as information retrieval and knowledge management. Findings indicated engagement and persistence on assignments - even at home. During interviews, students listed the laptop advantages: equal access to information, added interest in science lessons and improvement in achievements. Quantitative data showed significant elevation in agreement with phrases that express sense of self efficacy as shown in figure 1. Similar results were obtained for other variables such as control of learning, external and intrinsic motivation, etc.

2. Findings indicated improvement in quality of science teaching: Teaching goals were reviewed, effective ways to include ICT in classroom practices were developed: intensive use of animations, simulations and search for information "on the spot" when required.

3. Teachers reported that they could offer better and more effective ways of learning to their students - meeting individual learning needs among students in science classes.

4. Most science teachers reported on progress in professional development, increase in self-satisfaction and self-motivation although their work load was increased substantially.

Conclusions and Implications

The findings of this research add unique and positive evidence to the growing body of research regarding ICT integration in science studies, and especially one-to-one models. Personal laptop computers are very powerful in the science classroom and enable the teachers and the students to construct and enrich their understanding. Yet, it is not clear to what extend. This study contributes to the understanding that positive effects on students and teachers can be achieved only as part of balanced, comprehensive initiatives that address changes in education goals, curricula, teacher training, and assessment.
PROMOTING DIALOGIC DISCUSSIONS WITH A TECHNOLOGY-BASED PEDAGOGY

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Introduction

In this study we analyze the discourse in a classroom piloting an innovative teaching approach. This approach integrates Technology Enhanced Formative Assessment (TEFA) pedagogy, which accompanies the use of Classroom Response Systems (CRS), with the Thinking Journey (TJ) method. This pilot demonstrates how the combined approach encourages effective classroom discussions that improve middle school students’ understanding of complicated science concepts.

Rationale

In a typical classroom discussion the teacher asks a question, a student is selected to answer and the teacher evaluates the student’s response (I-R-E pattern), providing little opportunity for students to voice their own ideas or comment on those of others and provides no bridge from everyday discourse to scientific one (Lemke, 1990). One of the goals of the Thinking Journey approach is to develop more dialogic classroom interactions and to reduce the IRE patterns. TJ based activities introduce scientific contents in a specially designed dialogue of students with the teacher and with other students around pre-chosen photographs. The teacher facilitates students with the required information and tools for understanding (Schur and Galili, 2009). Similar to TJ, one of TEFA’s main characteristics is dialogical discourse, in alignment with the sociocultural approach to learning. CRS technology in TEFA is designed to promote dialogic discussions in question cycles. This technology offers several benefits: It provides both anonymity and accountability (Fies & Marshall, 2006), motivates students to answer, assimilates the spectrum of answers, and motivates class-wide discussion (Beatty et al. 2008).

Our hypothesis is that the use of an approach based on the integration of TJ principles with TEFA pedagogy and technology, will lead to effective classroom discussions. The research questions are:

- How does the combination of TEFA with TJ affect classroom discourse?
- How does the discourse affect student understanding of science concepts?

Methods

A pilot study was conducted in two 6th grade classes with a total of 37 middle school students. The teacher participated in TEFA professional development, and received personal preparation to use the TJ approach. The researchers developed an astronomy unit that incorporates the principles of TJ with the pedagogy of TEFA, around the topics of day and night and the cause of the seasons. The teacher implemented discussion-oriented pedagogy using photographs and a classroom response system. For example, the students observe photographs that show the moon and earth in different times and from different perspectives, and discuss the concept of day and night on the earth and its moon. The lesson took 4 days, and all classes were observed and videotaped. In addition, students completed pre-post conception surveys, and an attitude survey at the end of the unit. For analysis of classroom dialogue we used the communicative approach of Scott & Mortimer (2005), which identifies each episode of classroom talk as being either interactive or non-interactive on one hand, and dialogic or authoritatitive on the other.
The emerging four categories provide a tool for specifying the nature of the communication in classroom discussions.

**Results**

Four lessons were analyzed, where more than fifty percent of the discussions were coded as Interactive-Dialogic. The summarizing discussion in each lesson is always an authoritative discussion, in addition to some discussions where the teacher presents or summarizes a new concept. In general there were more Interactive-Dialogic than other type of discourse, and the level of participation was high.

The content survey findings revealed that 75% of the students were able to provide scientifically correct responses after instruction, compared to only one student before instruction. In addition, the percentage of naïve conceptions regarding the cause of the seasons held by students reduced from 91.9% before instruction to 21.6% after it. Student attitudes to the new approach were generally positive, with only 3 students saying it was difficult.

**Conclusion and Implications**

The integration of TEFA with TJ promotes interactive and dialogic discourse in the classroom. Although the concepts of day and night and cause of the seasons are difficult, the use of CRS and the focus on photographs lead to high level of students' engagement and enabled more students to participate in classroom discussions. The combined approach facilitated concept understanding and resulted in positive attitudes.

A limitation of the study is the need in intensive preparation of teachers to use the combined approach, and support in the first lessons. The teacher in this study was closely supported by one of the researchers. Therefore, there is a need in effective and sustainable professional development accompanying the combined approach.
COMPUTERIZED USE OF THINKING JOURNEY (TJ) MODE OF INSTRUCTION AS A MEANS TO OVERCOME STUDENTS' EGOCENTRICITY AND ENHANCE THEIR CONCEPTUAL UNDERSTANDING OF THE DAY-NIGHT CYCLE

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Introduction

The combination of the computerized Digalo (Schwarz & de Groot, 2007) as a graphical tool for representing argumentative moves in on-going e-discussions and the Thinking Journey (TJ) mode of instruction (Schur and Galili, 2009; Schur, Galili & Shapiro, 2009) were used. TJ enables students to get various perspectives on considered scientific concept. The teaching provides cognitive scaffolding for the learner in discussion on the presented visualized situations (pictures, video-clips, models etc). Students' curiosity is encouraged by pondering questions, guiding students' exploration and construction of the target knowledge which emerges from generalization of various perspectives. The Digalo application was used to provide an electronic medium for sustaining collective argumentation. The present study focuses on learning the concept of day/night cycle.

Methods

Thirty-two Grade 8 students from two junior-high schools in Jerusalem participated in the study, which was conducted as a part of regular lessons in science. All students were requested to participate to small groups synchronous e-discussions on the concept of day/night along the TJ scenario.

Students' conceptual learning was measured in three manners:

1. We adopted a pre-treatment-post paradigm with pre and post questionnaires. We checked knowledge construction through: (i) Correctness of knowledge – whether students' answers were more correct after the program; (ii) Elaboration – whether answers were more elaborated after the program; (iii) Mental models – whether the mental models of the students improved; (iv) Egocentricity – whether students' view became less egocentric; and (v) whether the answers became simpler, less context-bound.

2. We also examined the effects of mediation on learning through the analysis of discussions in class. Some of the groups received mediation from the teacher, some from the experimenter, and some received only peer mediation.

Results

In order to check whether there were differences between classes before the activity we conducted a MANOVA analysis. There were no differences between the classes prior to the activity in any of the independent variables. Another MANOVA of 2 (class 1, 2) * 2 (time – before, after) *3 (mediator – none, teacher, experimenter) was conducted in order to confirm the first research question. Results showed an improvement in all dimensions of the first research question following the Thinking Journey activity, except for the correctness of the answers that showed only a tendency towards improvement (F = 3.61, p = 0.068). Students’ answers were more elaborated (F = 7.85, p = 0.009): students knew more correct details after the activity compared to the situation before the activity. Most students (over 60%) did not hold the scientific model after the activity, a fact which explains why not all answers were correct. Still, there was an improvement in the model (F = 7.64, p = 0.01), which is a substantial
progress in the structure of knowledge that was obtained through argumentation in the TJ interactions. There was an increase in the universality of the day and night concepts following the activity (F = 18.40, p < 0.001) – students could see it as less related to the earth and more general. A correlation between the type of mental model and egocentricity was also found (RPearson = 6.06, p < 0.001), so that the less egocentric someone is, the more advanced is his/her mental model. No effect for class or group was found. Finally, students answers became simpler and more parsimony (F= 4.64, p= 0.041), and they gave closer explanations to the same phenomenon in different contexts. The results of the first research question brought good news: conceptual learning of a scientific concept in an environment integrating argumentation with TJ mediated interactions.

In relation to the second research question, we also analyzed the mediation moves, (such as presenting the main questions, challenging students' views, encouraging participation, focusing the discussion, enforcing the discussion rules) in the discussion by the following parameters: Mediator, Mediation type (content/organization), Location (beginning/middle/end), Type of approach (general/personal), Type of relating in mediation (wide/specific), Directedness of the teacher, and Quality of interventions of students (deep/ superficial).

The findings show that there was no effect of the location of the mediation on the quality and number of responses it received. Also, all mediators were very active in all parts of the discussions, and their involvement was in many times crucial for the continuation and development of the discussion. The mediation moves that dealt with content (referred to the task) received deeper responses (F = 22.24, p < 0.001; Beta = 0.405, p < 0.001) but fewer responses (F = 29.66, p < 0.001; Beta = -0.263, p < 0.001) as compared to organizational mediation moves. The same is true for a personal approach in mediation, which received deeper responses (F = 22.24, p < 0.001; Beta = 0.371, p < 0.001) but fewer (F = 22.24, p < 0.001; Beta = -0.495, p < 0.001) as compared to a general approach. Finally, wider mediation moves received deeper (F = 22.24, p < 0.001; Beta = 0.326, p < 0.001) and more (F = 29.66, p <0.001; Beta = -0.432, p < 0.001) responses than a specific approach.

The second research question enabled us to see that mediation was essential for the continuation of the discussions. If the mediator focused on content it enabled the students to better understand the concepts, but organizational mediation enabled the students to get more responses. The ability to focus the mediation towards specific students enabled students to give deep responses. When the mediators were able to see the wide picture of the conceptual development they got deeper responses from the students.

**Conclusion and Implications**

Results showed conceptual learning of the scientific concept. One could see that TJ interactions in the computerized version allowed students to mediate efficiently to their peers. The visibility of evidence in the TJ interactions used for the discussions lessened the egocentricity level since evidence and collective discussion was made part of the individual's cognitive space. By doing so, students could elaborate superior mental models. And indeed, we found a correlation of \( r = 6.06 \) between egocentricity and mental model. One can consider that this result can be explained from the specific way in which TJ mediated interactions are constructed to enable students to observe phenomena from a variety of perspectives and to connect scientific concepts with observation of specific environments. Integrating between the argumentation idea and the Thinking Journey mode of instruction, enabled to establish mediation is seen as a social dialogic activity.

The quality of a discussion needs to find balance between content and organizational mediation. Content mediation is crucial for maintaining quality to discussion as it is responsible for its depth but integrating this hardcore mediation with organizational mediation is a must: Wider mediations receive deeper and more responses, but the mediator shouldn't stay at this level alone. It is probably preferable for the mediator, as seen in most discussions, to begin with a wider approach, and to move down to the details with more specific questions.

The study showed that one can use computers as a means to establish dialogue and conceptual learning through the use of the TJ instructional method.
General Conclusions and Implications of the four studies

All the above studies relate to educational interventions that took place in regular classes. The computers and technology are not the focus of attention but serve as means to implement educational ideas, and are all connected to general theories of teaching and learning. The first paper emphasizes the need to use a variety of means (animations, pictures, audio explanations and textual ones) in order to be able to teach scientific concepts in heterogeneous classes. The second research emphasized the need to flexibly use computers for 24 hours and give the students learning tasks as a means to reach scientific literacy. Papers 3 and 4 emphasize the importance of classroom interactive dialogue. CRS technology enables the teacher to focus the classroom dialogue by getting real time information on students’ knowledge. The Thinking Journey (TJ) idea for constructing classroom interactions allowed the students investigated in papers 3 and 4 to have a broad understanding of scientific concepts, to get out of their egocentric view of the concepts and to have a universal understanding of scientific laws and understand how they are represented in a variety of contexts and environments. The following table illustrates the different uses of computers and technology in the different studies that were presented above:

Modes of instruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Technology</th>
<th>Pedagogy</th>
<th>Mediation</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multimedia with animations, vocal and verbal interventions</td>
<td>Experiments for understanding physical concepts</td>
<td>Organization of understanding based on the means of communication</td>
<td>Technological and Conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Personal laptops</td>
<td>Inquiry, multi – media. 24/7 use of laptop computers.</td>
<td>Teacher as facilitator and advisor</td>
<td>Developing scientific and information literacy</td>
</tr>
<tr>
<td>3</td>
<td>Classroom Response System (clickers)</td>
<td>TEFA+TJ to promote effective discussions</td>
<td>Using photographs to present multiple perspectives of the same concept.</td>
<td>Conceptual understanding</td>
</tr>
<tr>
<td>4</td>
<td>Digalo – discussions between 4 students and a mediator</td>
<td>TJ - Perspective changing in surprising environments</td>
<td>Comparison of different representations</td>
<td>Conceptual understanding</td>
</tr>
</tbody>
</table>

We would like to acknowledge our colleagues Prof. Dr. Verena Pietzner, who intended to participate in the symposium but eventually could not come to the conference, and Dr. Zahava Scherz, who contributed important insights to the symposium as a discussant.

General References


**Abstract**

Using an inquiry-based pedagogy during laboratory sessions often implies that the learners design experiments in order to answer a question or test a hypothesis. Due to the difficulties encountered, learners need help for achieving this kind of task. The objective of the study is to evaluate the efficiency, in terms of task completion, of a computer environment that provides scaffolding for experimental design in chemistry. In the studied software, scaffolding is provided at different levels: the experimental procedure is pre-structured for the learner, and an artificial tutor evaluates the learner’s production on his demand. From the log files of 76 first year university students, we studied the efficiency of this software on their success to complete the task. We also looked at the influence of the artificial tutor usage on the students’ activity, by limiting the number of accesses to the tutor and the extent of the provided feedbacks. We found that, while the tutor limitation influences the strategy of the students in terms of amount and types of consulted feedbacks, the success to the task of experimental design is not different for both limited and unlimited groups, and remains high in the dedicated time of work.

**Introduction**

**Practical work and inquiry-based approach**

Laboratory activities should help students develop understanding of the complexity and ambiguity of empirical work (Committee on High School Science Laboratories, 2006). However students encounter several difficulties with laboratory work, such as understanding the goal of an experiment (Keys, 1999) or interpreting data (Millar, 2004). To overcome some of these difficulties, a recent report from the European Commission (2007) highlights the need to change the pedagogy in science education by fostering inquiry-based methods. Inquiry-based learning is not new in the laboratory, but was reintroduced in the programs around 1996 in the USA (Hofstein & Lunetta, 2003). An important aim of inquiry in the laboratory is to help students understand the link between theory and experimental activities (Millar, 2004).

**The activity of experimental design**

Using an inquiry-based pedagogy during laboratory sessions often implies that the learners design experiments in order to answer a question or test a hypothesis. Designing an experiment may help students to link relevant theory to experimental activities and facts. Different studies emphasize the importance of designing an experiment in a learning context. Neber and Anton (2008) observe higher-order cognitive activities (thinking) of
students facing such a task. Arce and Betancourt (1997) find that students show better understanding of concepts related to the experiments they designed themselves.

The question of the place of experimental design activities experienced by students in current practices has been explored. Tiberghien, Veillard, le Maréchal, Buty & Millar (2001) find that in high schools of five European countries, experimental procedures are specified by the teachers in 80 to 95% of the laboratories. In France, a recent study of teaching geosciences in high school shows that 29% of the teachers claim that they asked their students to produce their own experimental procedure (Sanchez & Prieur, 2007). As all tasks of design (de Vries, 2006), the task of designing an experiment is difficult for students; this may be a major reason why this activity is seldom devoted to students. Several difficulties encountered by students have been reported, including correctly analyzing the issue, putting the procedure into words (Marzin, d'Ham & Sanchez, 2007), dealing with the multitude of parameters describing the experiment (Puntambekar & Kolodner, 2008), taking into account the question of accuracy (Girault, Cross & d'Ham, 2007) or using the necessary conceptual knowledge they should master (Laugier & Dumon, 2003).

The objective of this study is to evaluate the efficiency, in terms of task completion, of a computer environment created for scaffolding the activity of experimental design.

Rationale

One objective of our team is to define the key features of environments devoted to the scaffolding of learners engaged in experimental design. During the past years we have tested several situations involving computers (d'Ham, de Vries, Girault & Marzin, 2004) or not (Marzin et al., 2007). The software, copex-chimie, used during the current study, derives from a previous one that controlled a robot for distance manipulation (d'Ham et al., 2004). For technical reasons, we abandoned the use of the robot, and we extracted the part devoted to the experimental procedures elaboration with the dedicated feedback mechanisms.
copex-chimie is a web-application (http://copex-chimie.imag.fr) in which the learners have to determine the concentration of the red dye in a grenadine syrup by spectrophotometric titration. To attain this goal, students must write an experimental procedure that can be read by the application in order to simulate the experimental results. To scaffold the activity of experimental design, copex-chimie pre-structures the procedure at two levels: (1) the procedure must be written following three steps (prepare the standard solutions; obtain the points of the standard curve; determine the concentration of the dye), and (2) the actions constituting the procedure are defined among a list of eight actions (e.g. make a dilution, measure an absorbance, ...). For each action added in the procedure, the parameters describing the action (two to five parameters) have to be set by the learner (see Figure 1). Within this system, a valuable procedure is composed by at least twenty six ordered actions with their adequate parameters' values.

Another strategy of scaffolding provided in copex-chimie, is constituted by the feedbacks given to the user, i.e. the evaluation of the procedure by an artificial tutor and the simulation of the experimental results corresponding to the procedure. An artificial tutor is accessible on demand to the learner (see Figure 2). It evaluates the procedure, step by step, following a constraint system (Ohlsson 1993), and it points out to the learner the errors detected in the procedure. Furthermore, the artificial tutor gives links to pages of courses related to the types of detected errors. It has to be noted that the learner can also access freely to these pages from a menu in the application. The teacher can initially constrain the feedback provided by the artificial tutor in two ways: the total number of accesses to the tutor can be limited during the session, and the level of detail for describing the errors to the user can be adjusted to two options, i.e. the number and the types of the detected errors, or the whole description of the errors. For example, if a learner prepares the solutions of his standard curve in a bad range of dye concentration, the artificial tutor would give the following message: "Step 1: you have one error related to the standard solutions". If the whole description of the error is selected by the teacher, an additional message would be available: "Step 1: the standard solutions are prepared with inadequate concentrations".

![Figure 2. copex-chimie with the artificial tutor frame opened: below the experimental procedure, is located the frame used for the tutor's feedback. A global evaluation is given step by step with gauges (left), and details are given for each error on demand to the learner (right).](image-url)
Without any limitation, the learners can ask copex-chimie to provide simulated results corresponding to their procedure. If the artificial tutor evaluates the learner’s procedure as close enough to the expert one, simulated results are given to the learner (see Figure 3). These results can be used for answering the initial question.

Figure 3. copex-chimie with a result window opened. The window above the main application displays an absorbance spectrum simulated by copex-chimie, based on the actions' parameters of the learner's procedure.

The two questions that are addressed by this study are the followings: does copex-chimie enable students to produce a valuable procedure in a dedicated time? What is the influence of the artificial tutor’s adjustment (maximum number of accesses to the artificial tutor, level of detail of the errors’ description) on the student’s completion of his task and on his strategy?

Methods

Trials with copex-chimie were performed in the University of Grenoble, France in January 2008 and January 2009 with 152 first year university students enrolled in a science curriculum. The context was an interdisciplinary course focused on experimentation, with eight lab sessions designed around the theme of water experienced through five disciplines. The students worked by pair in a computer room during two hours. The teacher briefly presented the work to be done with copex-chimie and then let the pairs of students work independently.

Different strategies of scaffolding were applied regarding the use of the artificial tutor: one set of students had a full access to the tutor (control group CG: unlimited access to the artificial tutor and complete description of errors) while the other students were restricted either in the number of accesses to the tutor (experimental group EG1: twelve accesses maximum) or in the extent of the descriptions of the errors (experimental group EG2: limited description of the errors). The number of pairs of students for each tutor's strategy is given in Table 1.
Table 1. Description of the different groups of students concerned by the study.

<table>
<thead>
<tr>
<th>Tutor's strategy applied</th>
<th>Maximum number of accesses to the tutor</th>
<th>Description of the detected errors</th>
<th>Pairs of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full (CG)</td>
<td>Unlimited</td>
<td>Complete</td>
<td>21</td>
</tr>
<tr>
<td>Limited accesses (EG1)</td>
<td>12</td>
<td>Complete</td>
<td>32</td>
</tr>
<tr>
<td>Limited descriptions (EG2)</td>
<td>Unlimited</td>
<td>Limited</td>
<td>23</td>
</tr>
</tbody>
</table>

Log-files containing the activity of the learners during the session were recorded. From these log-files, fifty-one indicators were extracted to describe the students' work with copex-chimie (e.g. number of accesses to course pages during the whole session or before they started to write the procedure, number of effective accesses to the tutor, etc.). The activity was recorded until students completed the task or during the whole session for the ones who didn't complete the task. One of these indicators, the "success indicator" that estimates the success of the students to write the procedure, has to be described more finely: this indicator is calculated as the ratio of the student's highest success score by the duration of his work. The student's success score is automatically evaluated by the artificial tutor each time the student requires access to the tutor. It is calculated by subtracting the scores of each detected error from a maximum of points (20) that would be obtained for a procedure without error. This score is then divided by the time needed for writing the procedure.

For evaluating the differences in the student's work between the three groups corresponding to the three tutor's strategy, we used a non-parametric method of analysis, the Kruskal-Wallis one-way analysis of variance by ranks. Indeed, the distributions of the studied variables do not follow a normal distribution and the variances are not homogeneous; it was thus necessary to use a non-parametric method of analysis (Sprent & Smeeton, 2001).

Results

Learners' success to their experimental design with copex-chimie

Surprisingly, the values obtained for the success indicator did not show any statistical difference (p-value>0.1) between the three groups: CG (ξ=0.26, SD=0.12), limited access group EG1 (ξ=0.20, SD=0.09) and limited error description group EG2 (ξ=0.21, SD=0.06). It has to be noted that the mean value of the success indicator for all the groups of learners is 0.22, SD= 0.09. This score is typically obtained for a learner who manages to produce in 91 minutes a complete procedure without errors detected by the artificial tutor (0.22=20/91). Compared to the two hours duration of the session, this result showed that the learners were able to produce a correct procedure in the departed time with the help of copex-chimie. Indeed, among the 76 pairs of students, 56 pairs succeeded, in less than two hours of work on copex-chimie, in producing an experimental procedure that was positively evaluated by the tutor.

Even if the tutor's adjustments did not change the success of the learners to their task, we analysed more precisely our data to see if the strategies of the learners were dependant on the tutor's conditions. Tables 2 and 3 show the indicators that were found to be statistically different (p-value<0.1) between the control group and at least one of the experimental groups (limited tutor access or limited error descriptions).
Table 2. Mean values of indicators showing differences (p<0.1) between the control group and the group with limited (12) accesses to the tutor.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>CG: full access to the tutor</th>
<th>EG1: limited accesses to the tutor</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of accesses to the artificial tutor</td>
<td>16.8</td>
<td>6.5</td>
<td>0.01</td>
</tr>
<tr>
<td>2. Number of accesses to the simulation</td>
<td>6.7</td>
<td>10.3</td>
<td>0.03</td>
</tr>
<tr>
<td>3. Number of consultations of the instructions before the start of the experimental design work</td>
<td>1.4</td>
<td>2.1</td>
<td>0.01</td>
</tr>
<tr>
<td>4. Number of accesses to course pages before the start of the experimental design work</td>
<td>1.9</td>
<td>3.6</td>
<td>0.03</td>
</tr>
<tr>
<td>5. Total number of accesses to course pages</td>
<td>7.2</td>
<td>11.0</td>
<td>0.09</td>
</tr>
<tr>
<td>6. Number of accesses to course pages from the course menu</td>
<td>5.2</td>
<td>9.3</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 3. Mean values of indicators showing differences (p<0.1) between the control group and the group with limited descriptions of the errors.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>CG: full access to the tutor</th>
<th>EG2: limited descriptions of the errors</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Total number of accesses to course pages</td>
<td>7.2</td>
<td>10.1</td>
<td>0.04</td>
</tr>
<tr>
<td>7. Number of accesses to course pages from the tutor feedbacks</td>
<td>0.5</td>
<td>3.1</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Learners' use of the feedbacks (tutor’s evaluations and simulations)

The limitation on the tutor’s number of accesses modified the strategies followed by the learners concerning their use of the simulation. As expected, learners from the group with limited access to the tutor (EG1) requested fewer accesses than learners from the control group (indicator 1: 6.5 vs. 16.8, p-value=0.01). We note that in the limited group, most of the students didn’t even use all of the accesses they were granted (12), imposing a stronger limitation on themselves. In order to compensate for the fewer accesses to the tutor’s evaluations, the learners in EG1 asked for more simulated results (indicator 2: 10.3 vs. 6.7, p-value=0.03). Indeed, the recourse to the simulation gives feedback to the students at two levels: firstly, the simulation can only run for a procedure that is partly correct and thus indirectly evaluates the procedure; secondly, the simulated results help the students to evaluate the procedure by themselves (e.g. a saturated spectrum is an indicator of a badly designed experiment).

Learners’ preliminary work before engaging in experimental design

Indicators 3 and 4 evaluate the work of the learners before they actually engage in their design work, i.e. they define the first action of their procedure. The results show that the learners of EG1, with a limited number of accesses to the tutor, did more preliminary work before engaging in experimental design than learners with unlimited accesses to the tutor (CG). It appears that lowering the number of available tutor’s feedbacks encourages the learners to consult more frequently the work instructions (2.1 vs. 1.4, p-value=0.01) and the course pages (3.6 vs. 1.9, p-value=0.03) before elaborating their procedure.
Learners’ access to course pages

The accesses to the course pages by the learners during the whole time of work on copex-chimie are evaluated by the indicators 5 to 7. Some expected results were confirmed by our data: learners in the group with limited description of the errors (EG2), consulted course pages from the tutor feedbacks’ links more frequently than the control group (indicator 7: 3.1 vs. 0.5, p-value=0.00). This is coherent with the fact that the tutor gives less precision to the learner about his errors, thus the latter needs to consult the course themes related to the poorly described error. Another expected result is that learners in the group with limited access to the tutor (EG1), consulted course pages from the course menu links more frequently than the control group (indicator 6: 9.3 vs. 5.2, p-value=0.05). This can be explained by the fact that with less access to tutor's feedbacks, learners preferentially access to the course pages by the course menu than through the tutor's retractions' links.

A less expected result is about the total access to course pages by learners during their work. It can be observed that learners from the two groups with limitations on the tutor access (EG1) or error description (EG2) consulted more frequently course pages than learners from the control group (indicator 5: 11.0 vs. 7.2, p-value=0.09 and 10.1 vs. 7.2, p-value=0.04). This result was expected for learners with limited description of the errors for the reason detailed above. But for the learners of the control group compared to the ones with limited access to the tutor (EG1), we expected that the course links given in the CG by the tutors’ more frequent feedbacks would have encouraged them to consult the course pages. Apparently, the learners contented themselves with the tutor description of the errors and did not explore further the course resources. On the other hand, learners with limited access to the tutor consulted more frequently the course pages in order to compensate for the lack of feedbacks due to the tutor's access limitation.

Conclusions and Implications

copex-chimie proved its efficiency for helping students to produce a structured and valuable experimental procedure in response to a scientific question, as most of the student managed to complete this difficult task during the time of the dedicated session.

Limitations on the artificial tutor (access restriction or limited description of the errors) had an effect on the strategy employed by students in term of consultation of the provided information, i.e. course instructions, course pages and feedbacks given by the tutor or the simulation. While the tutor’s limitations seem to have no effect on the success of the student for completing the task, we think that some of the learners’ strategies induced by the different tutor configurations could be more efficient in terms of learning outcomes. In this respect, the limitation on the number of accesses to the tutor (EG1) seems to be the most interesting path. Learners dealing with this configuration of copex-chimie did more preliminary work (accesses to course instructions and course pages) in order to understand the task they had to complete. On their own initiative, these students consulted more frequently the available resources (course pages) and finally, they made a more diversified use of the different feedbacks they could ask for (more accesses to the simulations). This hypothesis could be further tested in an experimental set-up where learning outcomes would be measured with learners using copex-chimie with different tutor’s configurations.

References


LEARNING GRAPHS AND LEARNING SCIENCE WITH SENSORS IN LEARNING CORNERS IN FIFTH AND SIXTH GRADE

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University of Amsterdam

Abstract

The simple interface €Sense in combination with the software Coach Lite allows for measuring and graphing temperature, light, and sound. Distance sensor €Motion measures distance as a function of time. We developed activities with minimal text and a focus on the use of graphs as a tool for communication. Forty grade 5 and 6 children participated in a temperature activity and a distance-time graphing activity. Children worked in pairs in a learning corner and were video and audio-taped and their graphs were automatically saved on the computer. Children’s ability to read and interpret and communicate with graphs was tested in a pre-post test and through a post interview. Children could work productively with sensors and graphs in a learning corner. They could read graphs and provide simple interpretations of events. Four weeks after the distance graphing activity, 2/3 of the children could also sketch a graph of the interviewer walking with correct representation of movement, speeds/slopes and time. Confronted with a sound sensor and sound graphs they had never seen before, most (60%) children were able to suggest sensible ways to use these as tools in a new situation, to determine the winner in a fast hand-clapping contest.

Introduction

Without data loggers one would not think of using line graphs in science experiments in elementary school. Making graphs by hand is tedious and difficult for young pupils and might obscure the science anyway. Pupils might see a graph as a collection of isolated points rather than a pattern or conceptual entity (Leinhardt et al, 1990). In a study with children from grade 6 – 12 Wavering (1989) supported his claim that Piagetian formal operations (logical reasoning) are necessary to construct line graphs. Data logging reduces the mental and physical effort children must invest in actually constructing the graph so that there is more time and attention for interpretation (Newton, 2000). Data logging also reduces the cognitive requirements for graph constructing. There have been quite a few studies on the use of data logging (also called Microcomputer Based Laboratory or use of probe ware) for secondary education but few for elementary education.

In the elementary school children do get acquainted with various types of diagrams such as bar and pie graphs. In some countries children will certainly encounter line graphs, but in other countries it very much depends on the school and teacher whether children encounter line graphs before the age of 12 or 13. Nevertheless, some studies have been conducted using line graphs produced by sensors in data logging. McFarlane et al (UK, 1995) studied the impact of data logging on the development of children’s ability to read, interpret and sketch graphs in classes of seven and eight-year-olds. Children exposed to data logging versions of the experiments did better than their peers who had used traditional apparatus. Zucker et al (USA, 2007) conducted a large scale study with 70 teachers and almost 1200 children from grade 3 – 8 to evaluate TEEMS2 modules (Technology Enhanced Elementary and Middle School Science) with quite positive results for the data logging activities. Within this large study there was a comparison of classes of 21 teachers with and without probe ware in grades 3-4, 5-6, and 7-8. The teachers taught the modules one year without probe ware and the next year used a technology enhanced version using probe ware. For 4 of the 8 modules tested, results were significantly better. In a very well controlled study
Nicolaou et al (2007) in Cyprus found that 4th graders with data logging experience did better in constructing and interpreting line graphs than their peers who had used traditional means. They also performed better on understanding phase transformations (freezing, melting, etc.). In short there is evidence that data logging activities can have very positive results at the elementary level and that line graphs can be used productively even at the grade 4 level (Nicolaou, 2007) and perhaps even below (McFarlane et al, 1995).

1a. Coach Lite screen with temperature indicated as a red column, a number, and a temperature time graph.

1b Motion sensor

1c. eSense with a microphone (left), a temperature (center) and light sensor (right).

Figure 1. The sensors and a typical screen.
In the Netherlands experience with data logging at the elementary level is still limited. Berg and Ellermeijer (2006) reported some preliminary experiments. Since 2007 there is a special plug-and-play sensor set - €Sense - with a sound sensor, a light sensor, a temperature sensor and a buzzer (Figure 1). €Sense makes use of the powerful Coach software platform developed for upper secondary MBL, however, many choices in the software can be hidden or automated so that first time users can start measuring within minutes. The results of measurements can be represented as coloured columns (like a thermometer), numbers, and as graphs of property (light, temperature, or sound intensity) versus time.

Over 30 activities have been developed for grades 4 – 6, ten of which were tried out with 280 children in computer labs in 2007-2008. The children very quickly learned how to handle the equipment and software. A limited evaluation through eight post interviews showed that the children could tell a correct physics story with given graphs and were able to reproduce given graphs by manipulating a sensor (Schweickert et al, 2008). In 2009 €Motion, a distance sensor was added to the collection and tried out in this study.

In this study we wanted to take an in-depth look at learning with sensors, also recording the learning process itself and using a pre-post test. Furthermore we decided to work in learning corners as most schools do not have computer labs and are not expected to have enough sensors to let a whole class work with them simultaneously. In such learning corners supervision by the teacher is less as the teacher will lead other activities with the rest of the class. How and what will children learn under those conditions? Our research questions were:

1. Can children work productively with sensors with the limited guidance available in a learning corner?
2. Can grade 5 and 6 children relate to the graphical presentation of data and can they use the graphical presentation productively?
3. Can children communicate using distance-time graphs produced by a motion sensor?
4. Can children transfer the experience with distance-time and temperature-time graphs to the use of sound – time graphs in a novel situation?

Methods

Instruments

The following data were collected:

1. Pre-post test on graphs (40 children grades 5 and 6)
2. Post interview on graphs (20 children grades 5 and 6)
3. Video and audio recording of all 40 children involved in the activities
4. Webcam audio/video recordings of student answers to worksheet/screen questions. At certain points during the activities a webcam is switched on and children are asked to report and explain their findings. These webcam reports are available for analysis. Their graphs are saved as well.

The pre/post-test on graphs was constructed based on the math book used at the two schools. The test was designed by Schweickert, checked/revised by the other authors, and inspected by one of the teachers. The purpose of the test was to check on the general understanding of graphs (pre test) and to check progress on a few selected items after the activity. No significant overall improvement was expected as only two sensor activities were conducted without any plenary follow-up in the classroom. The test items require children to identify maxima, minima, read values, explain the shape of a graph, interpret graphs and justify answers with a short sentence, and sketch a graph. The Cronbach alpha reliability coefficient for the pre test was 0.92 and for the post test 0.89. Question 1 has been included as Appendix A and is similar to the graphs in the pupil’s math book. Question 6 – reproduced in the results section- appeared only on the post test as it pertains to the distance sensor and children only encountered this sensor after the pre test.
In a post interview more than 4 weeks after completing the second activity children were asked to remember what they had done, state which activity they liked most, and tell what they thought they learned. Then they were asked reading and interpretation questions on two temperature graphs. Subsequently they measured sound versus time graphs which they had never encountered before. They were asked to make some sounds for example by clapping their hands. Then the interviewer posed the problem: you want to organize a hand clapping contest and find out who can clap fastest. How could you use this sensor and this kind of graph to determine the winner? This question was designed to assess whether children could use the sensor and graphs as tools in a new situation.

In the last interview question the interviewer walked backward and forward towards a make-believe distance sensor while counting (time) and the children were asked to sketch the graph of distance versus time and write explanations for each segment of the graph with respect to direction and speed of movement. The post interview was audio recorded and during the interview part of the responses were already noted on an interview sheet.

Samples

A pilot study was executed at an Amsterdam Montessori school where 47 children of two mixed grade 5 & 6 classes participated in a series of data logging activities which at the time were still in development. Pre test, activities, and data collection methods were trialled there. The main study reported in this paper was conducted at an elementary school in Bussum, a suburb of Amsterdam with 27 grade 5 children and 13 grade 6. This is the research reported in this paper. Both schools were in middle class areas in their respective towns.

The math textbook of grade 5 contains some chapters about graphs and graphing. However, most schools/teachers/pupils do only part of this. There are bar graphs, pie charts and line graphs. In the country of realistic mathematics (Netherlands), all examples are taken from everyday life. They concern train travel, sports, visitors to amusement parks, and prices of products as function of amounts. Several problems deal with distance time graphs in the context of train travel. Pre test question 1 is very close to the questions children had practiced in their textbook, except that in the pre test question the towns and train schedules had been changed.

Activities

The children in pairs performed two activities which each took 20 minutes and were conducted on different days about 3 weeks apart. Activity one employed a distance sensor. Each pair was told that the sensor measured distance from the little box next to the computer screen to themselves. Then children further worked from written instructions while the researcher stayed in the background. They were given a graph on a computer screen and they were instructed to reproduce it by walking towards and away from the sensor. Each of the children in a pair got two trials, sometimes three. Then they were given a second and more complicated graph with the same instructions.

The second activity used the temperature sensor. Also here the researcher showed the children the equipment and then withdrew into the background and let the children work from written instructions which were also visible on the screen. Children measured the temperature at different locations in the mouth. At each location they measured for 50 seconds in order to achieve a stable temperature: 50 seconds between upper lip and tooth, 50 seconds against the ceiling of the mouth, 50 seconds under the tongue, 50 seconds on top of the tongue. When changing from one child to another, the researcher cleaned the sensor using alcohol and water. The resulting graph showed differences and values between 32 and 36 degrees Celsius. Under the conditions in a learning corner with little guidance, this activity did not produce reliable results. In both activities children answered questions on a webcam which started and stopped running when pressing the space bar on the computer. The graphs produced by the children were saved as well. Furthermore their interaction was recorded on video as well as audio.

The pre-test was administered in plenary in the classroom before the start of the first activity and the post-test in plenary a few days after the last activity. A few children were interviewed after the pre-test to ascertain whether questions were understood as intended.
Results

Some typical results of the distance – time measurement have been recorded in figure 2. Students were to walk such that their drawn graph (red on the screen) would be as close as possible to the given example graph (blue on the screen). This meant that they had to choose their starting position and make proper decisions with regard to timing, direction, and speed of movement.

Figure 2. Example results of distance – time graphs recorded by the children.

Pre-posttest scores have been recorded in table 1. The Cronbach alpha reliability coefficient computed with SPSS for the combined grade 5 and 6 sample pretest was 0.92 and posttest 0.89. We ourselves feared that the graphing test would be too difficult as a pretest, but it actually turned out to be too easy for grade 6 pupils with an average of 81% on the pretest. Scores for grade 5 pupils were much lower (average pretest 55%). With just two sensor activities we were not aiming at improving overall scores on the pre- and post test, but we did expect effects on selected items. Generally the children do well in reading the graphs. The most difficult questions are the ones on speed of motion (1g and 1h). Somehow grade 6 made great progress there while grade 5 did not. The most likely explanation apart from the grade difference is that grade 5 did the distance sensor activity 4 weeks before the post test and grade 6 only a few days before.
Table 1. Results pre-post test.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Grade 5 pre</th>
<th>Grade 5 post</th>
<th>Grade 6 pre</th>
<th>Grade 6 post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>55</td>
<td>60</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td>Range</td>
<td>27 – 80</td>
<td>30 - 93</td>
<td>50 - 93</td>
<td>64 - 93</td>
</tr>
</tbody>
</table>

Table 2. Pre-post results item 1.

<table>
<thead>
<tr>
<th>Grade</th>
<th>pre/post</th>
<th>1a</th>
<th>1b</th>
<th>1c</th>
<th>1d</th>
<th>1e</th>
<th>1f</th>
<th>1g</th>
<th>1h</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>pre</td>
<td>0.93</td>
<td>0.69</td>
<td>0.91</td>
<td>0.67</td>
<td>0.89</td>
<td>0.78</td>
<td>0.19</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>post</td>
<td>0.93</td>
<td>0.69</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.63</td>
<td>0.26</td>
<td>0.15</td>
</tr>
<tr>
<td>6</td>
<td>pre</td>
<td>0.92</td>
<td>0.62</td>
<td>1.00</td>
<td>0.88</td>
<td>0.85</td>
<td>0.88</td>
<td>0.46</td>
<td>0.38</td>
</tr>
<tr>
<td>6</td>
<td>post</td>
<td>1.00</td>
<td>0.73</td>
<td>1.00</td>
<td>0.77</td>
<td>1.00</td>
<td>0.92</td>
<td>0.77</td>
<td>0.77</td>
</tr>
</tbody>
</table>

The distance-time graph problem 6 in the post-test was more complicated and caused more scatter in the children’s results. The problem is as follows:

Somebody asks you to help to imitate the graph above by walking. There is a distance sensor next to the computer. The child who has to walk the graph, cannot see the screen. Below fill in the instructions how the child should walk, for example 6 seconds fast forward or 3 seconds slowly backward, or 5 seconds standing still. First ………... Then ………... Then………… Then………… Then………… Etc.

The percentage correct ranged from 54% to 90% for segments A – G in grade 6 and 35 – 72% in grade 5. The most common errors were in timing (for example 5 s instead of 6 s for segment A) and in slope (not indicating whether motion was fast or slow).

Figure 3. Distance vs. time graph.
Table 3. Percent correct on post test questions involving direction, standing still, time and speed

<table>
<thead>
<tr>
<th>Grade</th>
<th>Direction</th>
<th>Standing still</th>
<th>Time</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>41%</td>
<td>75%</td>
<td>55%</td>
<td>41%</td>
</tr>
<tr>
<td>6</td>
<td>81%</td>
<td>100%</td>
<td>90%</td>
<td>77%</td>
</tr>
</tbody>
</table>

Of the grade 5 children 41% answered questions about direction correctly while 25% consistently answered the reverse direction. This last group did distinguish consistently between the two directions. Grade 6 had done the temperature activity in March and the distance sensor activity in April a few days before the post test while grade 5 had followed the reverse order and did the distance activity 4 weeks before the post test. Apart from the fact that grade 6 had more exposure to graphs in their mathematics, this could be one of the causes of the remarkable difference between the two groups. In the interview which took place by the end of May, the differences between the two grade levels was much less pronounced.

In the post interview children were asked to sketch a distance time diagram of a backward/forward motion of the interviewer, slowly away from and rapidly towards an imaginary motion sensor. The intended sketch is shown in figure 4. Please note that the children had not sketched any graphs themselves in the activity with the distance sensor. 89% of the grade 5 and grade 6 children distinguished correctly between forward motion, backward motion, and standing still. 67% of the grade 5 and grade 6 children also correctly distinguished between fast and slow motion through a difference in slope. Errors were mainly with the slope of the graphs. The motion (figure 4) was a simple one compared to the post test problem 6.

Rita from grade 5 was doing math at the grade 4 level and had not yet encountered line graphs in her math program. In the interview she sketched the graph perfectly (figure 5). On the post test question she got all the speeds correct but made mistakes in direction and timing of the motion to get a score of 4.5 out of 7 on the post-test item.

![Distance-time diagram](image_url)

Figure 4. Distance vs. time graph.
Figure 5. In the upper figure Rita sketched the interviewer's motion. The lower figure is from the interviewer while Rita indicated whether motion was slow (‘langzaam’) or fast (‘snel’).

Please note once again that this is the result of only one 20 minute activity with distance-time graphs which had not been followed up in class. A plenary follow-up after all children have done the activity and a brief revisiting of distance – time graphs a month later could lead to substantial improvements yet.

**Reading and interpreting graphs:** 89% of the grade 5 and grade 6 read the correct values in interview graph A (figure 6). All of the grade 5 and 67% of the grade 6 children provided acceptable manipulations of the temperature sensor to obtain the given graph. When told how graph A was actually made, 89% of the 5th graders and 67% of the 6th graders provided an acceptable explanation for what was done differently to create graph B (either use more hot water, or use hotter water than in A). A typical interview answer was: Thijs: *In B you added a lot of hot water and then some cold. Asking explicitly for the difference: Here (in B) you added more warm water. Rita had an interesting answer. In A you first had the cold faucet on, then added the hot faucet to get lukewarm water. In B you turned the hot water on and turned the cold water off. And this would result in the higher temperature reading of B.*

**Using graphs in a new context:** In the sound task children recorded a graph of sound level versus time and were asked to suggest how sensor and graph could be employed to decide on the winner in a fast hand clapping contest. They had never used the sound sensor or sound graphs.
Iris (I, grade 6) had no problem.

I: Let everybody clap their hands in a separate room so that there can be no sound from the others, then clapping and all have the same time and then you can look how often they clapped.

Interviewer (Int): What will you count?
I: How many curves there are. …

Iris then recorded a measurement of her clapping

Int: Do you just measure for 1 s?
I: Just count all the stripes, everybody 10 seconds.
I: 1st second how often, in the 2nd second how often and third etc. until ten and then you compute the average.

Several other students in grade 6 also explained that counting claps for a longer time (10 s) rather than counting 1 s only, was a better way to assess the result of the contest and then you take the average… or …you divide by 10….

On the other hand there was Thijs in grade 5. Thijs was very clever when the sound sensor was introduced. He right away volunteered how the sound sensor might work after having made sound and seeing the pattern on the screen he said: I know how it works, air pressure. When you clap there is such a sound, there comes a wind and when you talk there are waves. The interviewer asks how he knows. Well, I just know.

Thijs (T) also correctly measures a time interval between two claps which he reports as 1 and 4/5 second, with reference to the stripes on the time axis. However, when it came to the clapping contest, Thijs kept being sidetracked by the height of the graph (sound intensity) rather than the time axis. Thijs reacts:

T: You can measure that. If you clap like this (he claps slowly) and if you clap like this (he claps fast) then when you clap like this (slow again) then the graph goes down while if you clap like this (fast) then it goes up. And indeed, when clapping rapidly, the next clap occurs before the sound level has gone down completely and so the average level of the graph is higher.

Int: Suppose somebody claps much slower, what do you see then?
T: then it goes down more

Int: When it comes very high, what does that mean?
T: That I am clapping louder

Int: but it is about faster clapping, how can you see that?
T: Oh, that it is a bit equal.

T: I see it already, here it is going slower, if I do this (fast) and then this (slow) then it is staying more equal (he means a horizontal curve) as there is more in between.

Int: but the point is who is fastest.
T: now you are asking me something.
T: you can see it from the upper one, if I do it like this (slow) then the peaks are higher and when like this (slow), then the peaks are lower.

Then Thijs suggests a way of having person A clap and then person B and overlaying the graphs (can be done with the software). We record the clapping of the interviewer and the clapping of Thijs in the same graph with different colors.

Int: Who clapped louder?
T: I (correct)

Int: Who clapped faster?
T: I think you

Int: Why?
T: Because with you I see fewer white parts in between, with you it is less white
Then we zoom in. The interviewer illustrates the counting and the conclusion is clear.

Int: *It would still be easier if you count just the peaks*
T: *I have been sleeping!*

Thijs is able to come close to the solution, but not a handy one. He does use the graphs, he also offers the idea to overlay the graphs of two competitors, but keeps being trapped in the height of the graph rather than the time dimension. Most grade 5 children did better and proposed to measure the time between two successive claps and if that is small, then you win. Some also proposed to put graphs of two kids on top of each other and with different colours. That way you also see. Valery of grade 5 did get the frequency idea. She right away proposed to count the peaks. *The more peaks, the more you clapped. Then you can also see whether you clapped more than somebody else.* When the interviewer presented an example of somebody who clapped 15 times in 10 seconds and somebody 15 times in 15 seconds, she right away indicated the real winner.

Overall 7 of the 12 interviewed grade 6 children were able to outline correctly how they would go about using the graph to decide on a winner of the fast clapping contest. Five of the seven used a process of averaging over a number of seconds and pointed out that averaging is better than just counting for 1 second. Five of the 9 interviewed grade 5 children were able to present a solution of whom one would measure the time needed for a fixed number of claps (correct) and the other would measure the number of peaks in the graph.

**Discussion**

1. *Can children work productively with sensors with the limited guidance available in a learning corner?*

   The children can learn to handle the equipment and computer within minutes. They can read the graphs and make simple interpretations. Most children clearly learned from the activities as evidenced in the post interview on the distance sensor. The mechanisms to transfer the necessary computer skills from one pair of children to another worked quite well. However, it is important that the teacher once in a while walks by and asks some questions about the activity and that the teacher organizes a brief plenary session to review and articulate the learning outcomes of the activity. This did not happen in our case. In future research we will focus on how to increase the minds-on level in learning corner activities.
2. Can children relate to the graphical presentation of data at the grade 5 and grade 6 level and can they use the graphical presentation productively?

Children can relate quite well to the graphical representation of sensor data, even Rita who had not encountered graphs before. The immediate connection between phenomena and their graphical representation works wonders. Some experiments with 4th grade children and studies by others (Nicolaou et al, 2007; McFarlane et al, 1995) suggest that even children at lower ages can use line graphs productively. However, on the more complicated questions there are large differences between grade 5 and grade 6 students. This happened particularly on the distance-time graphs (problems 1 and 6) in the post test. There are two potential explanations. The first one is simply the grade 5 and 6 difference. The second is that the grade 5 motion sensor activity took place as first activity one month before the post test while the grade 6 motion sensor activity was their second and took place a few days before the post test. On the post interview one month after the post test, 70% of the grade 5 and grade 6 children was able to sketch correct graphs with both correct direction, timing, and speed.

3. Can children communicate using distance-time graphs produced by a motion sensor?

We had not used motion sensors in grades 5 and 6 before, but they enjoy the motion sensor activities and understand the graphs. Controlling graphs and making them do what you want is challenging and fun. As indicated above, 2/3 of the children can correctly sketch a graph of a simple motion of the interviewer with direction and speed of motion correct. With some extra exercise and a plenary activity for closure (not in our research), results could be further improved yet.

4. Can children transfer the experience with distance-time and temperature-time graphs to the use of sound – time graphs in a novel situation?

2/3 of the 5th graders and 2/3 of the 6th graders were able to suggest sensible ways to use the newly encountered sound graphs in judging the fast hand clapping contest. 6th graders did have qualitatively better solutions as 5 out of 11 interviewed emphasized frequency and averaging results over time while 5th graders were more inclined to measure time between two claps.

Next steps in development and research should be to design a joint science-math curriculum line for teaching graphs integrating the use of sensors and testing this.

References

Activities: [www.pollen-europa.nl](http://www.pollen-europa.nl) and then choose EuroSense, over 30 activities about temperature, light, sound and distance.


### Appendix Item 1 of Pre-Post test

This is a distance-time graph of two trains traveling from Rotterdam Central station to Gouda.

- a. At which station is the commuter train 11 minutes after departure?
- b. Why is the graph horizontal (flat) at that place?
- c. How many kilometers did the commuter train travel in the first 11 minutes?
- d. How long did the commuter train travel to cover the first 10 km?
- e. How much time does the trip from Rotterdam Central to Gouda take with the commuter train?
- f. How many minutes shorter is the trip to Gouda by intercity compared to the commuter train?
- g. Between which two stations does the commuter train go fastest?
- h. How can you see where the commuter train goes fastest?
Abstract

A huge amount of excellent computer aided teaching and learning (CAT) material already exists in Europe, but there is far less experience and competence at using and choosing these materials effectively. This is especially true with respect to getting girls and boys interested to study science, and motivated to get acceptable learning results. Recent research results from science education show, that there are good chances of improving the classroom practice if the materials are appropriately used and adapted to the specific needs within the schools of the different countries. A transfer of those results into teaching practice within Europe will be organized by our project. International scientists and teachers, experienced within this field, work together and adapt their nationally oriented ideas and research results to those needs. The intention is to design and test modules for a teacher-training course, which enables teachers to judge the quality of CAT environments in science teaching, to adapt best-practice examples of those environments to their own teaching, and to evaluate it afterwards. For this purpose, we use already existing environments of the different project-countries. We will show that discussing and judging the quality of CAT for science teaching is an actual question in all European countries. The project is realized with support of the LLP program of the European Union.

Introduction

All over Europe, teachers have multiple possibilities to use computer aided teaching and learning (CAT) environments in their science classrooms. These are offered by companies selling teaching material, by schoolbook
publishers, and by university and teacher training establishments. However, for all this often confusing multiplicity of offers, teachers are left almost without assistance. Despite the existence of numerous results from relevant educational research indicating the criteria for evaluation, selection, and adaptation of learning software these are not available in a format that can be used efficiently by teachers.

Similarly, we observe that in the European countries there is a widespread need to find appropriate methods to evaluate the implementation of CAT environments, in ways compatible with local culture and local educational practice.

The 2008 call for projects in the Lifelong Learning Programme (LLP) highlights that “there is a need to promote and reinforce teachers’ skills and knowledge to make best use of the new opportunities created by digital educational content and services of all types, (...). Projects should focus on the development, testing, and implementation of materials, courses, and new pedagogical methods designed to improve the use of good quality digital content in teaching in schools, (...).” (European Commission 2008) The CAT project directly focuses on this priority in order to improve science education within European classrooms, especially to increase the motivation and interest of both, boys and girls, in science and technology. Recent research results from science education show, that there are good chances of improving the classroom practice if the materials are appropriately used and adapted to the specific needs within the schools of the different countries.

Based on these arguments and needs, the intention of our project was and is to design and test modules for a teacher-training course, which enables teachers to judge the quality of computer aided learning environments in science teaching (module 1), to adapt best-practice examples of those environments to their own teaching (module 2, module 4), and to evaluate their own teaching within their practice (module 3).

**Rationale**

Survey

Creating a teacher training course cannot be regarded as a one-way street – from theory to practice. The success and failure also depends on many different and complex contextual conditions to be taken into account (Kirkman 2000; Lavonen et al. 2006 a, b). Besides communicating latest results and findings of international research to teachers and helping them to find means of implementation, an international teacher training course has to address as well the different needs, requirements, competences and also hardships of the teachers (McFarlane & Sakellariou 2002) as it has to align itself with the diverse cultural habits and the different actual practices of the teachers. For economic as well as contextual reasons we opted for a survey based on an electronic questionnaire – according to (Bortz & Döring, 2006) – electronic questionnaires do not have an influence on the answers given.

Criteria for ICT

As we know, usable media (textbooks, web pages, databases, web encyclopaedias, educational multimedia etc.) should be special for teaching science, as learning depends on the quality of the media. The pedagogical orientation of teachers also affects the usability of the media. Other factors such as previous in-service training influence the media usability. “Usable media” is complex as concept, being hard to analyze without considering the users of the media and the educational context. According to “How People learn: Brain, Mind, Experience, and School” (Bransford et al. 2000) meaningful learning engages students in tackling the topic to be learnt in such a way that they create meaningful and understandable knowledge structures on the basis of a goal of learning. It is possible to present an outline of use of “usable media” in learning and based on “Multimedia learning” (Mayer et al. 2001). These suggestions and other recent findings are used to design a theoretical basis for our course, and to choose and judge examples along those criteria.
Conventional models of professional development are problematic because they tend to be fragmented, incoherent and disconnected from the daily work of teachers and students (Hawley and Valli 1999). A proposition for such a model is introduced and discussed below. It should take into consideration the difficulty: (1) to close the gap between the current and potential uses of technology for science instruction (Singer et al. 2000); (2) to have teachers to integrate ICT and student activity. Teachers need to be helped to link ICT and the subject matter, to learn how to interact with each other when preparing their teaching, and to focus on student learning. (Garet et al. 2001; Hawley and Valli 1999; Richardson 2003; Wilson and Berne 1999). Teachers need to develop new skills to change his/her classroom practices and should not add ICT into his/her old pedagogy, but change the use of their knowledge into a new class organisation. The model of professional development we propose below is hence based on four salient features as claimed by Singer et al. (2000): active construction, situated cognition, community and discourse.

Evaluation of learning outcomes by teachers

A professional teacher possesses (Altrichter, Krainer, 1996) the: (a) Attitude towards and competence in experimental, constructive and goal-directed work (action); (b) Attitude towards and competence in reflective, self-critical and systematically based work (reflection). (c) Attitude towards, and competence in autonomous, self-initiated and self-determined work (autonomy). (d) Attitude towards and competence in communicative and cooperative work with increasing public relevance (networking). Action research is the systematic reflection of one’s own work and professional situation in order to improve it (Elliott, 1991), Moreover, it is a continuous process of learning and changing, planned, executed and evaluated by those who are directly involved (Altrichter, Posch, 2006) In summary, it is simply a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practices, their understanding of these practices, and the situations in which the practices are carried out (Carr and Kemmis 1986: 162).

Course design

Newcomers to online instruction find that instructional design principles are very different for this medium. Principles that worked in a face-to-face environment or even over video/videoconferencing must be modified to facilitate online learning. Issues of social presence and immediacy behaviours are extremely important (Gunawardena and Zittle, 1997) and the role of the instructor as a facilitator/coach is critical. Now more than in traditional classrooms, distance education rely upon the student’s ability to be self-directed and motivated (Richards, Dooley, & Lindner, 2004).

Methods

A transfer of research results into teaching practice within different European countries can only be reached by working directly with teachers and science educators in each of the countries. Thus, scientists and teachers, experienced within this field work together and adapt their nationally oriented ideas and research results to other needs.

The whole project consists of different steps and 15 workpackages:

First, we realised a Survey on the Application of Computer Aided Learning Environments in the participating Countries. Over the past years a tremendous development of the use of ICT in everyday life has been observed. What is less well known is how this development affected the teaching and learning in European schools. An OECD survey in 2004 found out that the use of ICT in education in most countries concentrates on sporadic information retrieval from the Internet. Only a minority of teachers regularly use standard tool applications. The
reason were difficulties in integrating ICT into classroom instruction, problems in allocating computer time for classes, and a lack of ICT skills and knowledge of teachers. We checked whether we have the same situation 4 years later. The survey on the actual “local culture”, with regard to the application of CAT environments in the different participating countries, provides fundamental data for our future course (see Welzel-Breuer et al. 2009).

The basic version of the questionnaire and the appropriate coding scheme have been developed in English and discussed with all partners at a common project meeting. The resulting version has been translated into the local languages by each country and then distributed to at least 50 science teachers of each country. The data are analyzed statistically and qualitatively in order to gain insights in the spectrum of conditions, needs and actual practises. The results of the survey also prove invaluable to form practical suggestions for the teachers participating in the course on how to handle ICT in-class.

The next step was and is the detailed design, testing in practice and evaluation of a teacher training course. For this purpose, we started to use already existing environments and experiences of the different project-countries. The authoring of the course thus follows the latest results emerging from research and development in science education, and will be made adaptable to teaching practices in different countries and cultures in Europe. The production of training material and the collection of best practice examples is organised within an intercultural communication process during the lifetime of the project.

For the course module 1 we will develop criteria-dimensions and criteria inside the dimensions for choosing usable media for science learning and teaching, and to generate from this an interactive and adaptable teacher-training module. Therefore, literature, recent research results, and examples of media have been reviewed and analyzed. As we know, usable media (textbooks, web pages, databases, web encyclopaedias, educational multimedia etc.) should be special for teaching science, as learning depends on the quality of the media. The pedagogical orientation of the teachers also affects the usability of the media. Other factors such as previous in-service training influence the media usability. As said before, “usable media” is complex as concept, being hard to analyze without considering the users of the media and the educational context. The expected criteria are to be used to describe the best practice examples that we will present in our course (module 4).

The key of well-using ICT in classrooms (module 2) is an understanding of teachers about the reasons of using ICT, of the teaching/learning objectives they aim to achieve, of the possibilities or degrees of freedom these technologies afford to students. The aim of this module is to give guidelines to teachers for implementing the use of ICT in their teaching. It is grounded on learning hypotheses, coherent with those displayed in module 1, and which must be applied in the integration of an ICT-based disposal in instruction as in its choice by the teacher. It is necessary to distinguish two levels for ICT implementation in classrooms: during a session, in an immediate interaction with the software; at the scale of a whole teaching sequence. At the session scale, some questions must but envisioned: The distinction between computer-based measurements and simulations, the modelling power of simulations: it must correspond to a “modelling awareness” of the teachers, the way to manage classroom interactions in the case of ICT settings; in particular, the necessity for the teacher to take into account the (socio)-cultural inequalities among students regarding the use of ICT; and giving to teachers the possibility to accept the change in their role induced by ICT, from the unique source of knowledge towards a helper for students. Questions to be posed and answered at a long-term scale are: How to take into account the necessity for students to get accustomed to the software, the coherence of the uses of ICT through a given teaching sequence, and the evaluation aims and procedures. An other objective of this module is to take advantage of the various situations in Europe, depending on the level of equipment, of teacher training, but also of different cultural traditions. We think that giving an insight into the diversity of using ICT in Europe can help teachers to broaden their perspectives, but also to become more conscious of their own tradition, in order to surpass it or to assume it. The work consists of an analysis of existing literature on the topic, and in experiments in classrooms. Some experiments in teacher training sessions will be done.
The aim of module 3 is to introduce teachers to action research methods when using ICT in classrooms. Material for teachers who want to evaluate the effective use of ICT in their class will be developed, together with a good practice example for self-evaluation. Teachers usually evaluate the learning outcomes of their students by oral or written tests. In doing that, they fail to learn about the problems students face when learning science, their misconceptions, and the ways they collaborate with each other. The aim of this module is to help teachers to evaluate their own teaching by action research methods. How action research can be used in a teacher-training course is a secondary aim. Up to now, we have accumulated experience with action research methods in Austria, Germany, and France. This can be applied in the special situation of learning environments that integrate ICT. Some partner countries do not have any experiences with action research methods and teacher training that fosters these methods; altogether we will discuss and implement such methods into our training practices.

One of the main aims of the whole project is to show methods of implementation of computer aided learning environments in science lessons. It is, therefore, necessary to demonstrate examples of software that meet the criteria given in module 1. Each partner will evaluate examples of either already tested and highly recommended or new learning environments. The examples themselves and their evaluation with regard to the criteria developed will be made available in English or in such a format that allows changing the language into English (for example in html). From each participating country, 2 examples will be chosen and implemented in the teacher-training course. These will be translated into English, and commended as regards to the criteria and the methods of implementation used.

Together with this course, a teacher-handbook will be produced containing facts, criteria, methods of implementation, and of evaluation relating to the use of computer aided learning environments, and furthermore offering concrete best practice examples from the six European countries. The modules of the whole course can and will be offered “à la carte”, closely to suit the needs of the teachers who wish to implement CAT environments in science education, as they seem fit. Using the national teacher training networks within each of the participating countries, a team of experts will be able to adapt the designed course directly to teachers of the own countries and across country boarders.

**Results**

Interaction between researchers and teachers in Europe

An important key to for our project was and is the interaction within the consortium. The establishment of a constant and working communication between the partners was a crucial step to enable and stabilize all collaborative processes within the consortium. A huge benefit to achieve a working communication was the creation of a web based communication and working platform, which allows all partners and affiliated teachers to collaborate.

The collaboration with the teachers affiliated with our project also helped us to test the questionnaire and to understand more completely the teacher’s point of view on science teaching with new media. Their presence at our 2nd meeting in Plovdiv provided us with a pragmatic view gathered by years of experience on the job. We are in constant exchange with “our” teachers and try to discuss the all vital aspects of our course with them as detailed as possible. In addition, we will test our modules with them and listen to their critiques. This will be the next step of our project.
The survey’s data as a basis for our course design

The survey provided us with important hints for the course design. Looking at the results of the survey, we found teachers to be very interested in teacher training courses that reflect the real situations in school including problematic environments with malfunctioning hardware, network problems and missing software. There is a connection between the quality of hardware at school and the frequent use of ICT by teachers. The hardware situation in a school is an important and defining factor for teachers. The conditions show a wide variation between and within the different participating countries. The teachers in general feel not competent and confident enough to handle those situations on a hassling school day. If we could bring our teacher training course into schools, we could bring our expertise, ideas and knowledge into real life school conditions and at the same time grow more and more aware of the problems that teachers face every day, when working with CAT environments. Also this kind of teacher training setting allows for teachers to catch a glimpse of nearby schools that also are interested in the implementation of ICT within science lessons – this increases the chance of low-level networks and interschool partnerships. Our data also show that in general women estimate their self competence in ICT lower than men. That has to be taken into account, when organizing a training course and when offering materials. 3 possibly coexisting factor could be the reason: a lack of positive self reflection on their technical competency, boast or overestimation of men, or real difference in ICT competence. There is a connection between the competence teachers feel and their use of ICT. Our course needs to focus on confidence building as much as on competence building (see Figure 2)
The teachers wish to receive ready to use lessons and materials when participating in training courses. We found significant differences in the experience and variety of using CAT environment in science classrooms which can be used and transferred, and in the capacities of the teachers asked. In close collaboration with “our” partner teachers and our partners from the individual countries a look across the borders could help course participants to see concrete and new opportunities of ICT use in science classes, to adopt or develop new techniques themselves, to form partnerships, and to create virtual trading places for CAT environments. We will offer “our” best practice examples from six different countries and at the same time we will give space and use open platforms to include more and better ones.

Modules

The basic framework for our course has been set up. We will continue working along our initial plans. The structure of the course, which will be delivered in a blended learning design, provides an adequate combination of real live meetings and online modules. The final decision on how to schedule the online and real live meetings, will be made at our next project meeting in Lyon in December 2009.

Remark

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Contemporary Science Education Research: Teaching

References


EXPLORING EARLY CHILDHOOD TEACHERS’ ATTITUDES AND THEORIES REGARDING HOW YOUNG CHILDREN COME TO KNOW SCIENCE: SHARING FINDINGS FROM A CASE STUDY

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Abstract

Children are curious and try to figure things out and we can nourish their interest via offering them different and interesting science experiences. Several research related to teacher education has suggested that teachers’ classroom behaviors and activities are determined by a set of theoretical framework which is belief driven. In addition, different research indicated early childhood teachers’ needs to improve their knowledge regarding science education and to have more materials to do science activities. This study was conducted to understand teachers’ beliefs and attitudes regarding young children’s science education. The results indicated that teachers need more information about how children learn science and what are different instructional methods to teach science. From the results we conclude that early childhood teachers need a science education training program in which they could also have chances to have several materials.

Introduction

Children are curious and try to figure things out continuously. We can nourish children’s natural human capacity to know via offering them different and interesting science experiences (Harlan & Rivkin, 2004). Early years are the important years to develop critical and creative scientific thought processes (Watters & Diezmann, 1998).

Several research related to teacher education has suggested that teachers’ classroom behaviors and activities are determined by a set of theoretical framework which is belief driven (Clark & Peterson, 1986; Richardson, 1996). Research also shows that the structure and origin of scientific knowledge and knowing are related to individuals’ science learning (Edmondson & Novak, 1993). In addition, educational beliefs or value orientations appear to play an influential role in teacher judgments about what knowledge to retain in memory, providing individuals with selecting and storing information they consider most relevant and useful (Ennis, Cothran, & Loftus, 1997).

Teachers who had information regarding science education in ECE and applied them during their college education show positive attitude towards science education and feel comfortable during applications of science activities (Ünal & Akman, 2006). Another reserach conducted in Turkey found that a big portion of partipated early childhood teachers indicated not having sufficient material and information regarding science education (Karamustafaoglu & Kandaz, 2006). Early childhood teachers also pointed out that they need to be informed about the role of science education in ECE and different instructional methods they can use, and be supported in terms of materials they can use for science education (Karamustafaoglu & Kandaz, 2006; Ünal & Akman, 2006).

To develop a science education program and a support system for early childhood teachers, we conduct a pilot study in a child care. As a first step of the study, we interviewed with the teachers to understand their attitudes and theories regarding how young children learn science, and to learn their science education applications. In this paper we would like to share our findings from our case study.
Method

This study is first step of a longitudinal study which aims to develop a science education program to change early childhood teachers’ attitudes in positive way and to improve their practices. As first step of the study, we explore teachers’ applications and understandings regarding science education in early childhood. We conduct a case study with five early childhood teachers who work at one child care in Ankara. We had semi-structured interviews which composed of nearly 15 questions. All interviews were recorded by audio-recorder after obtaining participants’ permission. After transcribing audio-recordings of the interviews, three researchers did the content analysis separately and compared their findings and created categories according to their agreement.

The interviews were started with a warm-up talk. After that, questions from three previously decided categories were asked. These categories were about how young children generally learn, how young children learn science, and what these teachers’ applications are in science education.

Results

Findings were categorised in different areas. In this paper we would like to summarize findings in tables in which you can see and compare the information. Three out of five participants graduated from high school (P1, P2, and P3). Participant 4 graduated from a junior technical school and participant 5 had college degree. Participated teachers argue that sex and culture cause no difference in learning science, but socio-economical level is important in terms of having chance to visit different places and having materials.

Table 1. The Summary of Participants’ Answers about “How Children Learn Science”, “Provided Activities”, and “Needs Teachers Want to Have”.

<table>
<thead>
<tr>
<th>How children learn science</th>
<th>Activities</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Investigations by teachers taking children to visit some places make sure they see things providing materials work with parents cooperatively</td>
<td>Experiments grow a plant raising an animal visits zoo, where plants sold and some other places</td>
<td>More information and materials</td>
</tr>
<tr>
<td>P2 Make sure children experience things entertain and teach at the same time demonstrative things should be provided</td>
<td>grow plants, experiment, observation, going outside</td>
<td>More information and materials bigger classroom</td>
</tr>
<tr>
<td>P3 Children should be free to try what they want we need to use visual materials give explanations in a simple way; make sure they apply</td>
<td>use microscope and magnifying glass to investigate foods; projects, using internet, using cards about plants</td>
<td>More materials, more opportunities to go outside, more parent involvement, telescope, more books, growing plant in the garden, materials belonging to different countries, different rooms for each subject such as plants, space etc.</td>
</tr>
<tr>
<td>P4 Practicing and experiencing things Providing demonstrative materials Group work Supporting children’s curiosity</td>
<td>Activities with leafs making pickles grow plants, planting bringing an animal to class investigating bugs via magnifying glasses experiments</td>
<td>Books appropriate for children and encyclopedia less student in a classroom bigger classroom, microscope, magnifying glass for each child, different interest areas and rooms</td>
</tr>
<tr>
<td>P5 Doing experiment and investigation Visit different places Doing observation Be curious and ask questions</td>
<td>Projects are important, visits and observations, experiment, growing plants, raising animal, doing albums and collections</td>
<td>More materials, A child care in nature (e.g. in forest), Knowledgeable teachers, More parent involvement, More outside activities</td>
</tr>
</tbody>
</table>
Table 2. The Summary of Participants’ Answers about “How to Teach” and “The Role of Adults in Children’s Education”.

<table>
<thead>
<tr>
<th>How to Teach</th>
<th>The Role of Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P1</strong></td>
<td></td>
</tr>
<tr>
<td>It could be taught by using different and noticeable material and doing investigation</td>
<td>Love children</td>
</tr>
<tr>
<td></td>
<td>Being investigator</td>
</tr>
<tr>
<td></td>
<td>Open minded</td>
</tr>
<tr>
<td><strong>P2</strong></td>
<td></td>
</tr>
<tr>
<td>Simplifying the activities and through the play, it could be taught. Talking is very important so stimulating is very important.</td>
<td>Talk with children and provide materials</td>
</tr>
<tr>
<td></td>
<td>Encourage children’s curiosity</td>
</tr>
<tr>
<td></td>
<td>Teachers should know a little bit from everything</td>
</tr>
<tr>
<td><strong>P3</strong></td>
<td></td>
</tr>
<tr>
<td>For very young children, make it more fun and more demonstrative</td>
<td>Do some investigation, and prepare some teaching materials,</td>
</tr>
<tr>
<td>For older children, more information and explanation such as pictures from encyclopedia</td>
<td></td>
</tr>
<tr>
<td><strong>P4</strong></td>
<td></td>
</tr>
<tr>
<td>Giving children opportunities to do and experience Activities should be illustrated Curiosity can be encouraged in the group work</td>
<td>Supporting children’s development via activities</td>
</tr>
<tr>
<td></td>
<td>Supporting creativity</td>
</tr>
<tr>
<td></td>
<td>Giving previous information</td>
</tr>
<tr>
<td><strong>P5</strong></td>
<td></td>
</tr>
<tr>
<td>For younger children, using concrete materials and explain in a simple way For older children, giving more detail</td>
<td>Providing opportunities in which children can practice and experience</td>
</tr>
<tr>
<td></td>
<td>Taking advantage of informal learning experiences</td>
</tr>
<tr>
<td></td>
<td>Demonstrating</td>
</tr>
</tbody>
</table>

Conclusion

Participated early childhood teachers think that how to teach 2- and 3-years-old children should be different than the way chosen for 4- to 6-years-old children. They believe that teachers should provide materials, activities, and opportunities to children. These teachers indicate to need more information and materials to be able to support science education. Further analysis need to be done to see how teachers’ education and their own science experiences would be related to their beliefs regarding science education in early childhood. A science education program for early childhood teachers would improve teachers’ information and support their practices. It can also help them to create different materials in science education.

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CHILDHOOD SCIENCE EXPERIENCES RELATED TO SCIENCE EDUCATORS’ EPISTEMOLOGICAL BELIEFS: EXAMPLES FROM DIFFERENT COUNTRIES

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Abstract

Epistemological beliefs refer to one’s beliefs about the nature of knowledge and the ways of knowing. Personal epistemological beliefs are highly related to individuals’ beliefs about learning and teaching. Although research in this area has primarily focused on how the educational environments and academic practices influence individuals’ epistemological beliefs, we do not know enough about how early experiences and home environments could be related to individuals’ epistemological beliefs about science. We conducted a case study using in-depth interviews with seven science teacher educators in three universities from two different countries. The results suggest that educators’ own learning process in science is related to their epistemological beliefs about early learning in science. One of the findings from our study is that during their childhood these educators were exposed to multiple resources such as island tours, visits to the zoo, museums, parks, and the library. According to their beliefs, young children come to know science through multiple resources provided by family members and through the network they live in. Some of these resources include vegetable gardens, zoos, natural history museums, neighborhoods they live in, and books. Future research should focus on the connection between how individuals come to know science through their own experiences and their beliefs about how science becomes known.

Introduction

In the last decade, personal epistemologies have received increased attention from researchers and how individuals come to know the world is the starting point for epistemological beliefs research (Piaget, 1963). Epistemological beliefs are the beliefs about the nature of the knowledge (Chan & Elliott, 2004; Hofer, 2001).

Several research related to teacher education has suggested that teachers’ classroom behaviors and activities are determined by a set of theoretical framework which is belief driven (Clark & Peterson, 1986). This set of theoretical framework represents the teachers’ conceptions about teaching and learning (Calderhead, 1996). Because of this reason, teacher candidates’ or teacher educators’ beliefs about the nature of knowledge and knowledge acquisition (epistemological beliefs) have taken researchers’ attention. Studies on epistemological beliefs have indicated influence of these beliefs on one’s conception of learning and teaching (Broussseau & Freeman, 1988; Hofer, 2001). In addition, educational beliefs or value orientations appear to play an influential role in teacher judgments about what knowledge to retain in memory, providing individuals with selecting and storing information they consider most relevant and useful (Ennis, Cothran, & Loftus, 1997). Moreover, according to a group of researchers, epistemological beliefs could be domain specific.
Research also shows that the structure and origin of scientific knowledge and knowing are related to individuals’ science learning (Edmondson & Novak, 1993). Despite several research on this subject, still too little is known regarding how one constructs epistemological beliefs or how these beliefs are changed over time. In addition, we do not know enough about how early experiences and home environments could be related to individuals’ epistemological beliefs about science.

**Method**

In this paper, first, we focus on teacher educators’ beliefs regarding young children science learning and effect of different factors influencing this learning. Second, we examine the relationship between teacher educators’ childhood experiences with science related and their epistemological beliefs about science learning in young children. We conducted a case study using in-depth interviews with seven science teacher educators from three different countries, two of them (one female and one male) from a university in eastern USA, two of them (two males) from one university in central USA and three of them (one male and two female) from one university in western Turkey.

**Interviews**

The interviews were started with few warm-up questions regarding participants’ childhood science experiences. After that, questions from three previously decided categories were asked. These categories were about young children’s science competence, development, and individual differences.

**Analysis**

Transcriptions of audio-recordings of the interviews are content analyzed to identify the range and intensity of beliefs about the competence, development and individual differences relating to five years old children in the area of science. We also analyzed the answers of the teacher educators to the warm-up questions.

**Findings**

During analysis of the data, we discovered a relationship between science teacher educators’ childhood experiences with science and their beliefs about how young children come to know science. Three of seven cases were coming from same country and one of them was born in one country of the South America. Beliefs of the three science teachers’ educators were very similar. Following findings from the participants’ answers are presented.

First of all, during their childhood, they were exposed to multiple resources such as island tours, visits to the zoo, museums, parks, and the library. According to their beliefs, young children come to know science through multiple resources provided by family members and through the network they live in. Some of these resources include vegetable gardens, zoos, natural history museums, neighborhoods they live in, and books,
Table 1. The summary of participants’ answers about their own science experiences and their epistemological beliefs regarding young children’s science learning in terms of sources.

<table>
<thead>
<tr>
<th>Childhood Experiences</th>
<th>Beliefs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Safe neighborhood; alive animals; zoos; books; father’s job (hunter)</td>
<td>Need to be exposed multiple resources (books, toys, parks)</td>
</tr>
<tr>
<td>P2 Summers on a island; mothers’ experiments; sea animals; father’s support and questions</td>
<td>Created circumstances to investigate; national parks; parents’ love and support</td>
</tr>
<tr>
<td>P3 Natural curiosity; Cub Scouts; Encyclopedia, National Geographic, picture books</td>
<td>Need to be exposed multiple resources (books, toys, parks)</td>
</tr>
<tr>
<td>P4 School; mother’s teaching attitude</td>
<td>Need to be exposed books, games, science kits</td>
</tr>
<tr>
<td>P5 Questions of her father; Curiosity; Her father’s questioning attitude; Visits to big cities and museums</td>
<td>Curiosity; Family, teacher, neighborhood; Answer their questions; Talk with them; Museums</td>
</tr>
<tr>
<td>P6 Curiosity; Father as a model; Published material</td>
<td>Curiosity coming from birth; Support from others; Interest coming from birth; opportunities</td>
</tr>
<tr>
<td>P7 Interest Coming from birth</td>
<td>Innate interest</td>
</tr>
</tbody>
</table>

Second finding is that when they were children, they had hands-on experiences, read books, collected things, and observed different experiment results. To learn science, they believe young children should be constantly testing, having hands-on experiences, and reading books to be able to understand what is going on around them.

Table 2. The summary of participants’ answers about their own science experiences and their epistemological beliefs regarding young children's science learning in terms of activities.

<table>
<thead>
<tr>
<th>Childhood Experiences</th>
<th>Beliefs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Investigate in parks; observe animals; going to library; talk with father</td>
<td>Exploration in a safe neighborhood; using all senses in activities; parents’ talk about animals and plants</td>
</tr>
<tr>
<td>P2 Investigate in parks; observe animals; going to library; talk with father</td>
<td>Exploration in a safe neighborhood; using all senses in activities; parents’ talk about animals and plants</td>
</tr>
<tr>
<td>P3 Investigate in game club and backyard; collecting bugs, warms, leaves, rocks, pond water; using microscope; reading picture books; build model</td>
<td>Hands on activities, Outdoor science activities; exploring and investigating; reading science stories</td>
</tr>
<tr>
<td>P4 Mix stuff, make different colors</td>
<td>School experience; reading science stories</td>
</tr>
<tr>
<td>P5 Experiments at home with parents; observe animals in a village; observation;</td>
<td>Answer their questions; Do some experiments; Doing experiments at home; Try to find answer when face with unknown; Doing observations</td>
</tr>
<tr>
<td>P6 Try things out</td>
<td>Try to find answers about what they wonder</td>
</tr>
<tr>
<td>P7 Not too many activities</td>
<td>Questions coming from some changes</td>
</tr>
</tbody>
</table>

Third of all, the main role of adults and older peers when they were children was providing resources, supporting them, asking questions, and introducing new ideas. In their beliefs about young children’s science learning, adults and older siblings should be scaffolding, supporting, encouraging, asking open-ended questions, and modeling to try to figure out things.
Table 3. The summary of participants’ answers about their own science experiences and their epistemological beliefs regarding young children’s science learning in terms of roles of adults.

<table>
<thead>
<tr>
<th>Childhood Experiences</th>
<th>Beliefs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Create opportunities; model to investigate animals; talk and ask questions</td>
<td>Support curiosity by taking multiple places, spending time with them, and allow asking questions</td>
</tr>
<tr>
<td>P2 Create opportunities; model to investigate animals; talk and ask questions</td>
<td>Pointing things out; encourage for questions; provide multiple examples</td>
</tr>
<tr>
<td>P3 Provide resources, give them chance to do activities, create opportunities</td>
<td>Encourage for questions, help, guide</td>
</tr>
<tr>
<td>P4 Let him play around</td>
<td>Parents: Being model, provide toys, Teachers: being reference</td>
</tr>
<tr>
<td>P5 Talk and ask questions; Answer her questions; Creating opportunities to do experiments; Take her to big cities to see different things; Being model to read; Provide materials</td>
<td>Buying materials to do investigation; Answer their questions; Care what children are interested in; Take them to zoo, museums; Ask questions; Explain how things work</td>
</tr>
<tr>
<td>P6 Being a model as reading a book and creating technical materials; Let him try things out</td>
<td>Support children; Encourage their interest</td>
</tr>
<tr>
<td>P7 Protect from danger; Not do anything regarding science</td>
<td>Explain things in a way children can understand; Answer children’s questions</td>
</tr>
</tbody>
</table>

Conclusion

In some way, teacher educators’ own personal experiences with science are connected to their epistemological beliefs about early science learning. During their childhood, through hands-on experiences, they were provided multiple resources and encouraged to investigate scientific facts. In conclusion, they believe science knowledge is tentative and complex. According to their responses, the role of adults is to provide multiple resources and to allow children to think about facts, but not to give the answers. In addition, they believe children use multiple resources and ask questions to be able to find answers in science.

There is little empirical literature about teacher educators’ epistemological beliefs. This research study helps us to learn more about science teacher educators’ beliefs about how science becomes known. More research is needed to look closer at science educators’ own science learning experiences and their teaching and instruction in classrooms.

Findings stated that educators’ own learning process in science is related to their epistemological beliefs about early learning in science. Future research should focus on the connection between how individuals come to know science through their own experiences and their beliefs about how science becomes known. This knowledge would serve educators as they create and implement curricula for teacher training programs.

References


ENHANCING STUDENTS’ ABILITIES TO DESIGN EXPERIMENTS OF THERMAL INTERACTIONS BY VIRTUAL INVESTIGATIONS IN A SIMULATED LABORATORY

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Abstract

The aim of this study is to explore the effect of investigative activities with virtual manipulations in a simulated Physics laboratory, in students’ ability to design experiments, while trying to answer everyday life problems in the area of thermal phenomena. A pre-post comparison methodology was applied concerning written tests and personal interviews of 14 students in a lower secondary compulsory school in Greece, attending an innovative teaching sequence in thermal phenomena as part of their typical physics course. The teaching sequence had two main characteristics: the active engagement of students in laboratory activities, and the use of ICT, mostly involving investigations and virtual object manipulations using “Thermolab” - an Open Learning Environment suitable for the study of thermal phenomena. For the evaluation of students’ designs, their answers were rated in various dimensions. Our findings support the statement that there was improvement observed in our students’ skills to design experiments. Students after the course mostly use scientific criteria to articulate their hypotheses, make better choices about the variables involved and the settings, can more clearly describe the process and phenomena involved, and decide the criteria of their hypothesis verification more successfully. This is a new interesting aspect of the educational value of simulations, among the others reported, but not very widely investigated.

Introduction

Among various technologies, computer simulations and especially simulated laboratories have gained a lot of interest for science teaching. Research findings (de Jong, 2006) support their impact on conceptual learning. While literature is rich in studies investigating the conceptual understanding of students who are engaged in virtual manipulations, only a few of them deal with the development of experimentation skills. For example Triona & Klahr (2003) found that elementary school children learned how to design un-confounded experiments equally well when trained on either physical materials (using real springs and weights) or virtual materials (using a computer presentation of springs and weights). However, Finkelstein et al. (2005), while studying the effects of substituting a computer simulation for real laboratory equipment in the second semester of an introductory physics course, found that students who used the simulated equipment outperformed their counterparts both on a conceptual survey of the domain and in the coordinated tasks of assembling a real circuit and describing how it worked. While the above mentioned studies focus in the area of mechanics and electricity, there is not any work concerning the area of thermal phenomena and the development of experimentation skills in a virtual environment, which is the orientation of our study.

Involving students in laboratory activities in science courses is supported by most of the science education researchers and science teachers for it is believed to contribute not only in content knowledge but also in the development of a scientific way of thinking. Hodson (1992) suggests that students in the laboratory are “doing science”, which means that they are using the methods and processes of science to investigate phenomena, solve problems and follow interests that the students have. Unless one knows what to do (and why), and unless one has
the laboratory skills to do it, one cannot ‘do science’ – at least, not well and not successfully. Thus, the target for practical work assessment becomes doing science well. He defines a three element model, where one of the elements is: “the ability to plan & design “powerful” experiments that test or illustrate a theory in an elegant way”. According to Hodson planning an experiment is largely a concept-driven activity. It is the ‘thinking part’ of experimental inquiry. It includes several dimensions such as identifying a particular issue or problem for investigation, formulating a hypothesis, ascertaining the dependent and independent variables. “Designing” an experiment involves fitting a particular experimental procedure to the proposed investigation. It consists primarily of: making decisions about treatments, conditions, controls, specific measurements to be taken (and how frequently), techniques and instruments to be utilized, and so on. Both of these aspects of doing science can only be gained by experience of doing science either in traditional or simulated laboratories. “Planning” is also one of the three elements proposed for the assessment of laboratory work by Doran et al. (1993) which is used in a broader perspective (compared to Hodson’s) , and it involves: identify questions to investigate, describe strategy for investigation, describe how to measure and/or observe variables, plan for recording of data.

A broader view is also adopted in our research, when we refer to the “Designing” of experiments (we may note that in Greek language there is no discrimination between the words planning and designing). However, the description of the elements we propose for the assessment of this specific experimental skill, will make obvious that our rationale is very close to that of Hodson’s “planning & designing” of experiments. Our aim is to study the effect of investigative activities, which are based on a learning environment of virtual manipulations, on students’ skills to design experiments in the area of thermal phenomena. The research question of our study is whether the engagement of students in investigations in a virtual laboratory, can result in the development of students’ skills to design experiments in order to solve everyday life problems concerning thermal interactions of real objects.

Rationale

Investigative experiments were embedded in an innovative teaching in the area of thermal phenomena. The teaching sequence had two main characteristics (a) the active engagement of the students in laboratory activities and (b) the extensive use of ICT and particularly of a simulated laboratory “Thermolab”. “Thermolab” (Figure 1), is an Open Learning Environment, with the feel-and-look of a school laboratory (Hatzikrzniotis et al., 2001), suitable for active student engagement and the application of investigative experiments (Zacharia et al., 2008). Users can quickly and easily set-up and execute experiments by direct manipulation of the objects on the computer screen and observe the results in multiple representations & graphs of temperature and heat exchange vs. time. During the introductory phase of the course, students were engaged in some hands on laboratory activities in an attempt to get the feeling of thermal interactions. In some cases MBL sensors were also used and the real time graphs (both in MBL and in Thermolab experiments) provided a strong link between physical and virtual world.

Thermolab provided the environment for several investigative activities, which constituted the main part of the sequence. It should be stated that during the teaching sequence we deliberately followed a non-treatment approach for the experimental skills reported below in this work. These were only implied to the students during their laboratory investigations. In this way we can arrive to conclusions more clearly about the effect of the learning environment itself. Thus, “Thermolab” in our view, provides all necessary elements for experimentation, except from the actual physical manipulation of the objects. We consider that our students who use the virtual laboratory could develop experimental skills which are connected with science methodology and are included in the designing of experiments.
Methodology

A pre-post design was applied involving one typical class in a lower secondary compulsory school in Greece which agreed to participate and apply this innovative sequence. The subjects of our study were 14 students (13-14 years of age). The teaching sequence covered topics concerning Thermal Phenomena included in the Greek curriculum of compulsory education. Students had an adequate fluency in using computers and had a familiarization session of one hour, about “Thermolab”, before teaching. The science teacher was also experienced in the use of ICT. Students worked in pairs, each pair having their own computer and worksheets. Students’ achievement with respect to their ability in designing/planning of an experiment was assessed by personal written pre-post questionnaires followed by semi-structured individual in depth interviews. The post test was carried out one week after the completion of the teaching sequence.

For the assessment, students’ answers were evaluated in respect to the following characteristics, which we define as dimensions of the design of experiment. These dimensions are not listed in hierarchical order and were all considered of equal value for the scoring:

(1) Forming of hypothesis; what are the criteria of the students? (2) Hypothesis verification; what criteria do the students set, in order to decide if their hypothesis is verified or not (3) Variables’ identification; can they define the dependent & independent variables involved in the phenomena? (4) Devices, instruments & substances; what do students consider necessary for the conduction of the experiment? (5) Devices’ settings; which settings of the devices students’ set before starting the experiment? (6) Initial conditions; which conditions students’ set before starting the experiment? (7) Process description; how do students plan to observe and record the data? (8) Phenomena description; how do they describe the phenomena involved in the experiment?
Our research question is more specifically addressed by evaluating students’ answers in respect to the eight dimensions mentioned above, when they are asked to design an experiment. Pre and post tasks were similar, in the form of consecutive questions, about a real life problem situation, like the following: “Bill claims that milk gets hot faster than water. What do you think? How will you get the right answer? Can you set-up an experiment? What will you need? What will you observe? How will you decide if Bill was right or not?” In fact, we are asking the students to express hypotheses plan an experiment to verify it, write his/her answers and clarify and justify them during the individual interview, in which, materials like cups were available to the students.

In the literature, assessment frameworks can be found, concerning mostly the overall performance of students’ science process skills, or students’ inquiry skills or practical work. Several of these include parts that are addressing the students’ skills in planning or designing experiments. For example Josephy (1986), describes an assessment instrument called OCEA (Oxford Certificate of Educational Achievement). One of the four processes assessed by the instrument is “planning” and includes a number of dimensions such as: (students should) suggest a testable hypothesis, select appropriate apparatus from a range provided, suggest apparatus suitable to a task, develop a plan which, if carried out, would answer a simple problem. In our view, all dimensions should be equally assigned to the same number of levels and score, so we came up with a 3-level scoring scale, given the age and abilities of our students. For example, in the assessment of the forming of hypothesis, answers are evaluated in different levels, depending on whether they are poorly stated or they are based on alternative conceptions or based on scientifically accepted criteria. If a student’s answer in a given dimension is evaluated in level 1, then he gets 1 score point, in level 2 he gets 2 points and in level 3 he gets 3 points. For each dimension the answer corresponds uniquely to a given level. Such an approach resulted in a matrix of eight by tree, giving a score to each student between 8 (minimum), to 24 (maximum).

Results

In order to be assessed students’ answers were analyzed and categorized in the eight dimensions listed above by two experienced Physics educators. The raters marked independently the answers after coming to an agreement about the characteristics of each Level in all dimensions by defining a 3-grade scale (1, 2, 3=more successful). In some cases of disagreement between the raters these were resolved by discussion before the final scoring. Results show a considerable change, where mean score was 14.4 for the pre-test and 19.4 for the post-test, with standard deviation of 2.7 and 1.9, respectively for the pre and post test. Considering the values of standard deviation we can claim that there is an effect of our teaching sequence in the development of experimental skills in our students. In addition the smaller value of standard deviation in the post-test (1.9 < 2.7), shows that our students’ scores data follow a narrower distribution about the mean value. In conclusion, data analysis reveals that concerning the development of experimental skills, our teaching sequence had the effect of (a) students achieving higher mean score (b) distribution of scores about the mean value became narrower.

The Wilcoxon signed-rank test was chosen for non parametric statistics given the size of the sample. Analysis carried out, revealed a statistically significant difference beyond 0.1% level, between the pre and post students’ scores (z= -3.22, P(1)=0.0006 < 0.001). This supports the claim that there was a development in the mean scores of our students after the treatment (in the above mentioned level of statistical significance).

Concerning the Forming of Hypothesis dimension, a great improvement is observed. While initially most of our students (13/14) were expressing their hypothesis without justification or insufficiently or based on alternative conceptions, after treatment nearly all of them (11/14) are using scientific criteria to formulate their hypotheses, applying the knowledge acquired earlier.

The hypothesis verification criteria were successfully handled in the pre-test by only about half (8/14) of the students. On the other hand, at the post-test, the majority of the students (12/14) could clearly define a verification criterion and a few of them (2/14) could even define a second alternative criterion.
In the variables identification dimension while initially almost half of our students (6/14) could not define the dependent & independent variables, after the treatment most of them (10/14) could adequately define them and a few of them (4/14) could fully define the variables.

For the Device Settings dimension, we also observed an improvement. Initially most of our students (10/14) could set only a few of the necessary settings of the devices, but after treatment the majority of our students (13/14) could define most of the settings necessary for the conduction of the experiment.

Although there was quite a good level of success in the Process Description dimension even at the pre-test, we still observed some improvement. Initially, only about half of our students (6/14) were able to sufficiently describe the experimental process. On the other hand, after treatment nearly all of our students (13/14) were able to give a clear description.

The same as above applies for the “Phenomena Description” dimension, were there was also a slight improvement observed. In detail, initially about half of our students (8/14) described the phenomena involved in the experiment by expressing alternative conceptions while the other halve (6/14) used a description close to the scientifically acceptable. After treatment, almost all of our students (13/14) were describing the phenomena involved in a scientifically acceptable way.

In the other two dimensions, “devices, instruments & substances” and the “initial conditions” the improvement was not so clear, yet we could still observe a positive shift. This means that initially, the majority of our students could mention a few (6/14) or most (6/14) of the necessary elements for the conduction of the experiment, wile after treatment the majority of our students were able to mention most of the elements (8/14) or all of them (4/14). About the same comment applies for the “initial conditions” dimension. Initially, about half of our students (6/14) could not even mention any of the necessary initial conditions, after treatment a lot of the students (10/14) could mention many of the necessary conditions and some of them (4/14) could mention all of the conditions.

Conclusions and Implications

We consider that our findings support the statement that there was an improvement in students’ skills to design experiments in order to deal with real life problem situation concerning thermal phenomena. The above gain in students learning was accomplished following their engagement in a teaching sequence, in which they were involved mainly in investigative activities with virtual object manipulations in a simulated laboratory environment. The improvement is related to specific aspects of the design of experiment, where several of our students after teaching were able to formulate hypothesis with criteria that are scientifically acceptable, rather than intuitive; define in a more successful way the criteria to verify their hypotheses; recognize the dependent & independent variables better; define more adequately the appropriate initial conditions and settings of the devices; mention the necessary devices, instruments & substances more sufficiently; better describe the experimental process and mainly use a scientifically accepted description of the phenomena rather than expressing alternative conceptions.

The observed development, as we believe, could be mainly attributed to the specific features of “Thermolab”, as it offered students all necessary elements of actions on virtual objects in life-like manipulations, linked to the design of experiments, while giving the opportunity to easily test their designs. So this suggests, in our view, that some dimensions of experimental skills, namely the ones we defined as the design of experiment, can be enhanced by the use virtual laboratories. Such findings add to the pedagogical value, among the others reported in several studies, of virtual laboratories and their potential for facilitating students in doing science and developing scientific skills. Further research will be useful, in larger samples and other fields in order to explore the potential of virtual laboratories since they are easily handled by both teachers and students and, as open environments, can be flexibly integrated in science teaching (Petridou et al., 2005). They are not conceived as replacing hands on experimentation.
but as adding to the creation of enriched learning environments in which students are actively engaged in learning science and doing science.

References


Triona, K. (2003). Point and click or grab and heft: comparing the influence of physical and virtual instr. materials in elementary school students’ ability to design experiments. Cognition & Instruction, 21(2), 149-173.

Abstract

The transition from primary to secondary level is a critical change for the student and might be responsible for the decrease in interest and performance in Germany as it can be concluded from international comparisons studies. In this paper differences in science teacher characteristics and in student perceptions of science instruction between primary and secondary level are investigated. The underlying model that explains how each factor is linked to classroom activities and the resulting student achievement is based on the model of Helmke (2003). It describes teaching-and-learning-situations by an offer, made by the teacher, and how the students make use of this offer (offer-use-model). This offer might be dependent on the teacher’s professional knowledge. The first part of this paper is discussing the role of teacher’s content knowledge in the perspective of the offer-use-model. The second part addresses the question of differences between primary and secondary teachers’ pedagogical content knowledge. The third part describes classroom-management as one important factor that might moderate the effect of the offer-use-situation. Finally, the fourth paper investigates whether primary and secondary students differentially perceive science instruction as supportive for their understanding of scientific concepts.
Introduction

The papers in this chapter show different parts of one project, that is the PLUS-project (professional knowledge, teaching and learning in science, and students’ outcome in the transition from primary to secondary school). The intention is to describe relevant factors in teacher's professional knowledge, the way teaching-and-learning-situations look like and differences in the students' preconditions that could explain the difference between primary and secondary school level in Germany found by several studies (e.g. Hoffmann, Häußler & Lehrke, 1998, OECD, 2004; Bos et al., 2003). To link these factors from different levels (teacher, lesson, student), the model of Helmke (2003) is chosen. Helmke describes the teaching-learning-situation by an offer, made by the teacher and how the students make use of this offer. The quality of the offer is dependent on several variables, determined by the teacher’s professional education, knowledge and personality and the school context. The offer itself can be described by variables of lesson quality, like content structure, classroom management, scaffolding and so on. The students' perceive this offer and make use of it. If they can use it successfully is dependent on their preconditions regarding interest, motivation, pre-knowledge, cognitive abilities etc. Whenever they could use the offer, there will be an increase in interest and knowledge for the student.

The PLUS-project measures many of these variables and can therefore describe a congruent and wide picture of the offer-use-relation and its effects on the students’ outcome variables. All participants can use the results from all instruments that are developed in any part of the project. The data will allow a multi-level-analysis to answer the question, how the teacher's offer influences the students’ outcome and how the offer and its influence depend on the school level. In four different PhD-projects specific questions linked to this overarching question are investigated. In the following, the results from these four projects are reported concerning differences in teacher's professional knowledge, classroom management and teaching-learning-strategies between primary and secondary level.
TEACHERS’ PHYSICS-RELATED CONTENT KNOWLEDGE IN PRIMARY AND SECONDARY SCHOOLS

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Abstract
International studies reveal a decrease of students’ achievement and interest in science classes in German secondary schools. There are strong hints that the teachers’ content knowledge (CK) influences the quality of teaching and students’ learning outcomes and, that teachers from primary- and secondary schools differ significantly in their CK. In this study teachers’ CK is modelled using complexity levels for the difficulty and focusing on a specific topic – “states of matter and phase transitions” – and to use analysis of classroom videos to investigate the influence of CK on classroom teaching. The students’ achievement will be measured with a test in a pre-post design. So far the CK test has been developed and a pilot study has been conducted on n=80 teachers from primary and secondary schools. The development and first results of the CK test and a conception for the video analysis will be reported in this paper.

Introduction
This study is embedded in a larger project (PLUS-project), which focuses on the interface from primary to secondary school in terms of quality of teaching, teachers’ professional knowledge and students’ learning outcomes. International studies reveal that students’ motivation, interest and achievement have declined in German secondary schools from grade 5 to grade 9 (Hoffmann, Häußler & Lehrke, 1998, OECD, 2004; Bos et al., 2003). For primary schools the situation is different. In 2003 the international PIRLS study in Germany was extended with TIMSS science items and compared to the TIMSS 1995 primary results. The findings show that students in primary school perform significantly better than the international mean (Bos et al., 2003). In TIMSS 2007 those results could be confirmed. (Bos et al., 2008)

Rationale
The underlying model of the PLUS project is based on the model of Helmke (2003), which describes teachers’ professional knowledge as one influencing factor on quality of teaching and students’ outcomes. According to Shulman (1986), beneath four other features teachers’ professional knowledge includes content knowledge (CK), pedagogical knowledge (PK) and pedagogical content knowledge (PCK). Those three scales are seen as most important for the quality of a lesson. A recent German study – “COACTIV” measured the teachers CK and PCK and correlated it with students’ achievement and cognitive activation in the lesson, using home works and material used in the lessons as basis for analysis. According to this both, CK and PCK, are important predictors for students learning outcomes. Further more CK and PCK are not independent facets of teachers’ professional knowledge. The
understanding of scientific content and underlying concepts is a necessary requirement for the development of PCK (Baumert et al., 2006). Similar results could also be found in third grade mathematics classes (Hill, Rowan & Ball, 2005). Regarding teachers’ physics content knowledge there are hints that primary and secondary school teachers differ considerably in their CK (Wirz, Fischer, Reyer, & Trendel, 2005).

**Methods**

To measure teachers’ CK in primary as well as in secondary schools, a test has been developed to measure their CK at three levels of complexity: knowledge about facts, relations between facts and overarching concepts (Kauertz & Fischer, 2007). The content of this test is based on an analysis of primary and secondary school textbooks. To differentiate between high performing teachers, the content from books of university level was also included. Both dimensions are supposed to have an impact on the item difficulty. The following model clarifies the underlying dimensions of the teacher test:

![Figure 1. Model of the teacher test for content knowledge](image)

The test contains 42 items and was administered to teachers (n=80) from German primary and secondary schools in a pilot study. In this sample, 50.8% of teachers were female and their mean working time at school was 20.18 years.

**Results**

The reliability of this test was $\alpha=0.89$ (Cronbach’s alpha) and the mean item difficulty index was 66%. The expected difference in CK between primary and secondary school teachers could also be found. The teachers from secondary schools performed significantly better in the test than did the teachers from primary schools ($p<.001$).
A Rasch analysis showed that 39 of 42 items fitted to the model with \(-2, 3 < T < 1, 9\) and \(0, 78 < \text{MNSQ} < 1, 22\).

Those results revealed that teachers from primary school could solve mostly items on the level of primary school books and on the complexity level of fact and concept. This seems to be contradictory to the assumption that items on concept level are more difficult than items on fact and relation level.

Figure 2. Differences in content knowledge of primary and secondary school teachers

To validate the model (fig. 1) experts were asked to rate the test items. For the dimension of complexity the interrater-agreement is between \(0.61 < \kappa < 0.93\). For the dimension of content the agreement is between \(0.57 < \kappa < 0.89\) (Cohen's kappa). Those results indicate that it didn't succeed to develop model conform items and neither content nor complexity influence the item difficulty significantly in this test.

Conclusions and Implications

The results of this test raise the question of whether the differences corresponding to teachers’ CK can also be found in students’ learning outcomes. We assume that the relation between teachers’ CK and students’ achievement is mediated by the quality of teaching. Therefore classroom videos from primary school science classes will be analysed, regarding three different aspects of quality. One aspect is the content structure of the lesson which may indicate what aspects of a teacher’s CK are explicitly used in a lesson and how they are linked with each other to develop the taught content and its structure.

But not only highly and correctly linked aspects of the content is important for students’ achievement, but also the fit between the level of a teacher’s expectation and offer and the level of his or her students’ reactions and answers, which will be analysed in a second step (Lau, Neumann, Fischer & Sumfleth, 2007).

As third aspect of the quality of a lesson will be analysed to find which are the underlying aims and the structure of the lessons. Therefore the theory of basis models of teaching by Oser & Beariswyl (2001) is used. According to Reyer (2004) three basis models are most important for science teaching: learning through experience, problem solving and theory development. In a recent study an instrument for video analysis has been developed to evaluate a teacher training in those basis models in secondary schools (Wackermann, 2007). This instrument has been adapted for primary school lessons and will be used in this study.
PEDAGOGICAL CONTENT KNOWLEDGE (PCK) IN SCIENCE EDUCATION: A COMPARISON OF PRIMARY AND SECONDARY SCHOOL TEACHERS

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Abstract

Pedagogical Content Knowledge (PCK) is considered to be an important component of teachers’ professional knowledge. It seems to be likely that primary school teachers show poorer PCK than secondary school teachers, because they often lack of content knowledge, which is considered to be a prerequisite of PCK development. On the other hand, primary school teachers seem to be able to compensate for incomplete content knowledge. In our study we directly assessed primary and secondary school teachers’ PCK concerning “states of aggregation”. Results show no mean differences between the teachers groups supporting the assumption that primary school teachers are able to compensate their lack in content knowledge.

Background

The study presented here is part of the project PLUS that investigates conditions and outcomes of science teaching in the transition from primary to secondary school in Germany. The scope of this paper is teachers’ pedagogical content knowledge (PCK) in science education. PCK is considered to be a central component of teachers’ professional knowledge (Shulman, 1987). Recent studies support this assumption by showing that teachers’ PCK is strongly related to students’ achievement gains (e.g., Hill, Rowan & Ball, 2005). As in many countries, primary and secondary school teachers in Germany have taken part in completely different professional training for science teaching. Primary school teachers are characterized as being “generalists”, whereas secondary science teachers as “subject specialists” (Gess-Newsome, 1999).

Rationale

Against this background, it seems likely that primary and secondary teachers differ in terms of their science-related PCK, because PCK is described as a kind of ‘amalgam’ of content knowledge with pedagogical knowledge (Shulman, 1987). Magnusson and her colleagues (1999) proposed a model of PCK in the area of science education, differentiating between “orientations towards science teaching” and knowledge of “science curricula”, “students’ understanding in science”, “instructional strategies” and “assessment for science”. Concerning orientations towards science teaching, there is some evidence that primary school teachers are more ‘student oriented’ (Bryan & Atwater, 2002; Keys, 2005). However, studies that directly assess the further PCK-components according to Magnusson and her colleagues and compare primary to secondary school teachers’ PCK do not exist up to now. With regard to...
these PCK-components at least two argumentations are proposed: (1) Since content knowledge is considered to be a prerequisite of PCK development, a lack of content knowledge—as it is shown for primary school teachers—should involve a lack in PCK (Summer & Kruger, 1994, Ohle in this paper set). On the other hand primary school teachers seem to compensate for incomplete content knowledge. In order to be able to address students’ ideas, teachers seem to be triggered to improve their content knowledge and PCK (Akerson, 2005). Against this background we investigated differences in primary and secondary school teachers’ PCK.

Methods

In a preliminary analysis, data of 57 primary and 31 secondary science teachers were available. The whole sample of the PLUS project, which will be completed at the end of 2009, will comprise about 60 secondary teachers. In our study, secondary school teachers stem from two types of schools: Gymnasium (higher achieving students) and Hauptschule (lower achieving students). The study focuses on two components of PCK described by Magnusson et al.: ‘knowledge of students’ understanding of science’ (KSU) and ‘knowledge of instructional strategies’ (KIS). A paper-and-pencil-test (13 free-response-items and 3 multiple-choice-items) measuring these two components in the domain of “states of aggregation” was developed. Teachers were, for example, asked to list as many as possible alternative students’ conceptions about a special scientific topic (KSU). We also presented situations in which teachers were requested to detect students’ learning difficulties or to describe adequate behavior to promote insightful learning (KIS). Interrater-consistency for the open-ended items was satisfactorily high (ICC=.93) and so was the internal consistency of the test (Cronbach α = .69).

Results

A comparison of teachers’ PCK assessed by this instrument revealed no significant differences between primary school teachers and secondary school teachers. Moreover, we found no significant differences between teachers at Hauptschule and Gymnasium (ANOVA: p= .20, η²=.04).

Conclusions and Implications

Showing no mean differences in primary and secondary school teachers’ PCK, our results seem to support the “compensation hypothesis”: As Annika Ohle showed in this paper set, teachers, who participated in our study, had lower content knowledge than the participating secondary teachers. So, primary school teachers must have compensated for their lacking content knowledge when acquiring PCK (Akerson, 2005). Given the fact that there are no mean differences in PCK between the teacher groups, the question raises, whether individual differences account for teachers’ instructional practice in science teaching and for students’ progress in scientific understanding or interest. This question will be one of the next issues of the PLUS-project.
STUDENT PERCEPTION OF CLASSROOM MANAGEMENT IN PHYSICS LESSONS

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Abstract

Shaping the interfaces between different types of schools is a domain specific problem and a matter of research all over the world. Regarding Germany, large scale assessments show that outcomes of German students’ science learning decreases significantly when they change from primary to secondary school. E.g. in PISA 2000 and 2003 German secondary school students showed lower performance than the OECD average while in TIMSS 2007 German primary school students performed above the average of the participating countries regarding mathematics and science. Among other influences, this effect might be caused by the teachers’ classroom management which is expected to vary between primary and secondary teachers who have different educational backgrounds. In the presented study, classroom management is investigated by considering the students’ perception of their teacher’s management behaviour. Therefore, a student questionnaire consisting of three scales has been developed. The questionnaire has been used in primary (grade 4) and secondary (grade 6) science lessons with n=278 students. Data analysis shows that the expected differences between primary and secondary students’ perception of their teachers’ classroom management can be found on all considered scales. Primary school students describe their teacher’s classroom management significantly more positive than secondary school students do.

Introduction

In Germany, students need to attend school for at least ten years. During that time, their school career is divided into two main parts: primary and secondary education. In most German states, all children who are approximately at the age of six attend a general primary school for four years (grade 1 to 4). After that, they are separated into different types of secondary schools (grade 5 to 10) depending on their level of performance and on recommendations of their primary school teachers. There is evidence that particularly for science learning, lessons from grade five and onwards are on a more teacher- and theory-oriented level while primary school science classes are more student-oriented, often based on students’ experiences and contain many experimental phases (Hartinger, 2005; Tytler, 2007).

Results of international comparative studies like PISA 2000 und 2003 indicate that the performance of German secondary students and also their motivation and interest decrease significantly when they change from primary to secondary school (OECD 2001, 2004). This can not only be observed during the transition from one type of school to another, but also over the whole of secondary school up to grade 10. Although results of PISA 2006, whose main focus was on science education, showed an improvement of German students, there are still enormous gaps within certain types of secondary schools (especially on low performance level) and also between different types of schools (Prenzel et al., 2008). To date, the question about reasons for this decrease has not been answered by empirically proved studies. It might be assumed that a detailed investigation of science lesson quality could lead to finding reasons for the differences in students’ outcomes on primary and secondary school level. One aspect of lesson quality to be considered intensively in this respect is the manner of how teachers manage classroom
situations in order to guarantee a high amount of learning time during the lesson. In order to illustrate, why classroom management is expected to contribute to an explanation of the decrease on student outcomes in science lessons on different school levels, two perspectives need to be regarded. On the one hand (P1), it has to be clarified why classroom management is expected to contribute to higher quality of science lessons (more general perspective). On the other hand (P2), there is the more specific question: Why is classroom management of all aspects expected to lead to an explanation of the decrease in students’ motivation, interest and performance after the transition from primary to secondary school?

**Rationale**

The Impact of Classroom Management on Science Lesson Quality (P1)

Teachers’ classroom management is one of the most important parameters for successful science teaching and learning (Emmer & Gerwels, 2006). It is an essential factor of lesson quality which is directly associated with the level of students’ performance and improvement (Helmke, 2003; Wang et al., 1993). So establishing and applying a classroom management system consistently advances students’ academic performance (Evertson & Harris, 1992; Good & Brophy, 2003). Furthermore, disciplined and consistent leadership in classes proves to be relevant for the perceived motivational encouragement on student side (Rakoczy, 2006). Brophy (1986) accentuates the need of well organised classrooms “as an efficient learning environment where activities run smoothly, transitions are brief and orderly, and little time is spent getting organized or dealing with misconduct”. To deal with these challenges, teachers have to use lesson time as effective as possible by involving more or less all students in a classroom in the lesson, so that a high activity level concerning science contents can be guaranteed. Teachers have to prevent disruptions and to define clear and sensible rules, which students have to follow. Also, they have to clarify consequences for compliance and non-compliance. Therewith, classroom management is an essential teaching skill, which has to be guaranteed in science classes so that students can learn successfully (Henley, 2006). Making this grade is not only a great challenge for young but also for very experienced teachers who have been teaching for a long period of time, because frameworks of teaching keep changing and the heterogeneity of students increases appreciably (Schoenbaechler, 2008).

Besides the relevance of efficient classroom management for students, it is also very important for teachers that researchers conduct a more detailed empirical investigation of this topic. Surveys showed that having to deal with discipline problems is one of the most mentioned reasons for teachers to quit their job. Moreover, research indicates correlations between disruptive student behaviour and teacher burnouts (cf. Friedman, 1995).

Differences of Classroom Management on Primary and Secondary School Level (P2)

Although classroom management is regarded as a key function of teaching and learning, substantial differences between primary and secondary school teachers concerning this particular skill have been observed (Weinert, 1996). Also it has to be mentioned, that German primary and secondary school teachers’ educational backgrounds differ, as another possible reason for variances in their management behaviour. Research on classroom management is very rare, especially in European countries (Helmke, 2003). There are only few studies which use an operationalized definition of classroom management. Most studies provide a rather broad view with multiple facets.

Goals, Research Questions and Hypotheses

The idea of this study is to condense the existing framework to a measurable definition and considering physics specific aspects. Teachers’ classroom management is investigated by systematically comparing primary and secondary school teachers’ skills in this concern.

To identify aspects of classroom management relevant aspects must be analysed, reduced to an operationalized definition and then, in a next step, applied to evaluate primary and secondary teachers’ classroom
management. This leads to the following research questions: Does classroom management differ between primary and secondary school science teachers and – if yes – which differences can be identified? Therefore an instrument is needed to measure classroom management in science lessons independent from level of education. The restriction to only science related teaching is relevant because teachers have to have a high amount of professional content knowledge (CK) and pedagogical content knowledge (PCK) to manage a class efficiently.

The resulting hypotheses are

(H1) Primary school students describe their teacher’s classroom management more positively than secondary school students do.

(H2) There are not only differences between primary and secondary science teachers’ classroom management but also between lower and upper performance level in secondary schools (Hauptschule vs. Gymnasium).

**Methods**

**Model of Classroom Management and Science Learning**

In order to analyze the relation between teachers’ classroom management, the students’ perception of it and the students’ outcomes of a lesson, a model of Classroom Management and Physics Learning has been developed (see fig. 1).

Figure 1. Classroom Management and Science Learning.

The model illustrates the assumption that teachers’ classroom management, defined as a construct composed of discipline, rule clarity and prevention of disruption influences students’ outcomes like performance, motivation and interest during the lesson. But this relation itself is moreover influenced by the students’ characteristics they bring into the lesson (performance, motivation and interests they had before the lesson) on the one hand and by the students’ perception of the teachers’ management behaviour during the lesson on the other hand. Before this model can be validated in a following study, the aspect of teachers’ classroom management has to be clearly defined, and an instrument to measure this part of lesson quality has to be developed. This is the goal of the presented study. More details about the following study will be given within Conclusions and Implications.
Definition and Measurement of Classroom Management in Science Lessons

According to the development of the term of classroom management in the last 40 to 50 years, we define classroom management as a construct of three main aspects: discipline in class, rule clarity and prevention of disruptions. In general, the construct of classroom management has experienced lots of changes during the last thirty to forty years. In the 1960ies or 1970ies, the manner of classroom management was only focused on students’ discipline problems and how teachers should deal with them (Canter & Canter, 1976). Kounin’s techniques of classroom management (1976, 2006) and works of Emmer, Evertson & Anderson (1980) were the first approach of thinking about prevention of disruption rather than losing time by discussing disruptive behaviour and consequences to that in class. Nowadays, most of the educational books for teachers focus on both dealing with discipline problems and preventing disruptions, and also on integrating these aspects (Rüedi, 2002). In this respect, it is very important to apply a wide concept of rules and rituals in the classroom, which have been elaborated with the students themselves in order “to enhance their social and moral growth” (Evertson & Weinstein, 2006). Teachers should also help their students to learn about self regulation (Keller, 2008; Weinstein, 1999). So in this study, it is intended to identify and describe specific habits of science teachers and how teachers concretely operate in a classroom situation. This is reached by considering discipline, rule clarity and prevention of disruption. E.g. in the scope of talking about discipline, it is observed how often the teacher has to tell the students to be quiet before they actually become quiet. Concerning rule clarity it is considered e.g. how clear and sensible the rules seem to be for the students. One item regarding prevention of disruption is about the teacher being everywhere even if he or she only talks to a little group of students (Kounin, 2006).

One possibility to measure classroom management in science lesson is to ask the students about their perception of it; former studies on classroom situations showed that the students’ perception of the lesson is very close to the impression objective observers get of a lesson (Clausen, 2002). Moreover, there is evidence that students’ general impression of a lesson correlates with their achievements (Clausen, 2002). So in order to answer the question of differences in classroom management on different school levels, a questionnaire of Students’ Perception of Classroom Management (SPCM) has been developed. It is based on works of e.g. Clausen (2002) and PISA 2000 (OECD, 2001). According to the definition of classroom management in this study, the questionnaire consists of three scales: discipline, rule clarity and prevention of disruption. Each scale consists of five to six items. The students can evaluate their teacher’s management behaviour on a four point Likert-scale from “agree” over “almost agree” and “partly agree” to “disagree”.

Design of the Study

The sample (n= 278) was chosen from students in their last year of primary school and students in their first year of secondary school. Two types of German secondary schools are considered: Hauptschule – lower level of performance and Gymnasium – higher level of performance. Participation was voluntary and anonymous. University staff members went into the schools and did the questionnaire with the students by reading it out. That way, it could be ensured that even poor readers understand the content of the questionnaire. The accomplishment took about 25 minutes. The teachers have been asked not to walk around the classroom and watch the students’ answers. The students should get the chance to answer honestly without having to be afraid of consequences for their marks.

Results

The internal consistency of SPCM measured by Cronbach’s Alpha is $\alpha = .897$ for discipline, $\alpha = .811$ for rule clarity and $\alpha = .872$ for prevention of disruption. A factor analysis shows that the three constructs can be validly separated, as all items load on the assumed factor. A Rasch analysis also shows satisfying reliabilities on all scales. The item reliability is above .91 on all three investigated aspects of classroom management. The person reliability is .84 for discipline, .69 for rule clarity and .82 for prevention of disruption. Moreover the items have been reviewed
for misfit. A cut-off of 1.2 has been used. Only for the scales concerning rule clarity and prevention of interruptions, there has been one item each with outfit MNSQ above 1.2. This misfit has been accepted because of a content related explanation.

Table 1 shows the resulting means for each factor of the sample on school level. A MANOVA showed significant differences between all kinds of schools (Pillai’s Trace = .508; F = 31.07; df = 6; p < .001; η² = .25).

Table 1. Aspects of Classroom Management in Different Types of Schools.

For the scale concerning discipline in science related lessons significant differences were find between all types of schools. Primary school students describe the discipline in their science lessons significantly more positive than students from Hauptschule and Gymnasium do (p < 0,001). The difference between the perceived discipline in the different types of secondary schools (Hauptschule and Gymnasium) is also significant, but on the level of p < 0,005. Students from Gymnasium describe the discipline in their science lessons significantly more positive than students from Hauptschule do.

Rule Clarity in science related lessons: There are significant differences between primary school and Gymnasium (p < 0,001) and also between Hauptschule and Gymnasium (p < 0,001). But there are no significant differences between primary school and Hauptschule. This means that primary students as well as students from Hauptschule stronger confirm the clarity of rules and rituals in their science related lessons than students from Gymnasium do.
For the scale concerning prevention of disruptions again significant differences were find between all types of schools. Primary school students describe the preventive behaviour of their science teachers significantly more positive than students from Hauptschule and Gymnasium do (p < 0,001). The difference between the perceived prevention of disruptions in the different types of secondary schools (Hauptschule and Gymnasium) is also significant, but on the level of p < 0,005. Students from Hauptschule describe the prevention of disruptions in their science lessons significantly more positive than students from Gymnasium do.

Considering the three investigated types of schools, quantitative differences could be identified. It could be shown that classroom management has a higher weight in primary than in secondary schools. Especially the gap between Gymnasium and primary school is large. Rule clarity and prevention of disruption e.g. play a subordinated role in Gymnasium while they are more relevant in Hauptschule and primary school.

Conclusions and Implications

As the qualitative aspects of the instrument as well as the results of the study show, the student questionnaire presents an efficient observation instrument of teachers’ classroom management on different schools levels. The findings, that there are differences in classroom management in primary and secondary schools from the students’ point of view, do not lead to the conclusion that they contribute to an explanation of the differences in performance, motivation and interest of German students. They only lead to the need of a following study in a more comprehensive context. E.g. pre-knowledge as well as further aspects of teaching (teacher variables) have to be taken into account. This is done in a larger project (the PLUS-project) where the focus is not only on classroom management but on many different aspects of lesson quality. Because the study involves the video analysis of 120 lessons as well as doing tests and questionnaires before and after these lessons, student outcomes (performance, motivation and interest) can also be regarded. Concerning classroom management, the data of the PLUS-project allows evaluating certain classroom management characteristics that lead to an explanation of the decrease in student achievements (see fig. 2).

As figure 2 shows, student-teacher-interactions during a lesson at school are influenced by teacher variables like e.g. their pedagogical content knowledge on the hand and by individual learning premises on student side on the other hand. This again means that student outcomes are always influenced by all these variables, of which one is the teachers’ classroom management. By identifying central, observable factors of classroom management within this study, our findings can be used as a basis for developing further trainings for teachers concerning efficient classroom management. This could contribute to a stronger assurance of learning success for students and for better facilitation and support of work pressure for teachers.
Figure 2. Overview about Data of PLUS-Project.
PRIMARY AND SECONDARY SCHOOL STUDENTS’ PERCEPTIONS OF TEACHING FOR UNDERSTANDING

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Background

The study presented here is part of a project (PLUS) that is situated in the domain of learning and teaching of science in the transition from primary to secondary school in Germany. The conditions and requirements for teaching science in primary schools are very different from those in secondary schools (e.g., teachers’ background in science, curricula). For this reason, it has to be assumed that science instruction and students’ perceptions of lessons in science are very different at both levels. The focus of this paper is the question to what extent primary and secondary school students perceive instructional features as supportive for their scientific understanding.

Rationale

Teaching for understanding describes instructional features to support students’ acquisition of scientific understanding (Harlen, 1998). Teaching for understanding also requires encouraging conceptual change, embedding learning in meaningful contexts, scaffolding, and negotiating meanings and the relevance of concepts (Harlen, 1998; Duit & Treagust, 2003; Duschl & Hamilton, 1998). Simple transmission of scientific concepts is not assumed to promote the acquisition of understanding because it neglects the students’ cognitive activity (Harlen, 1998). Until now, there are no studies comparing students’ perceptions of teaching for understanding at primary and secondary levels.

In the German school system, the transition between primary and secondary schools takes place after year four. To cover the whole transition zone in the subject of science, this study invited year four and year six students to take part. The year six students, who are in their first year of secondary science, attend two types of schools: Gymnasium (Gym; with higher achievers) and Hauptschule (HS; with lower achievers).

Methods

In order to measure year four and year six students’ perceptions of teaching for understanding, a questionnaire was administered to 224 students (n(primary school) = 85, n(HS) = 59, n(Gym) = 80) for them to complete. The questionnaire consisted of five scales with three to eight items and Cronbach alpha reliability of the scales ranged from .66 to .77: encouraging conceptual change (cc) (6 items; \( \alpha = .70 \)), embedding learning in meaningful contexts (emb) (5 items; \( \alpha = .73 \)), scaffolding (sc) (8 items; \( \alpha = .71 \)), negotiating meanings and the relevance of concepts (neg) (3 items; \( \alpha = .77 \)), and transmission (trans) (8 items; \( \alpha = .66 \)).
Results

The performed univariate analyses of variance ensured that there were significant differences between the groups of primary and secondary school students regarding their perceptions of teaching for understanding in the five scales: cc ($p = .00, \eta^2 = .05$); emb ($p = .00, \eta^2 = .10$); sc ($p = .00, \eta^2 = .27$); neg ($p = .00, \eta^2 = .07$); trans ($p = .00, \eta^2 = .10$). The results showed that the primary students perceived science instruction in all five features as more supportive for their scientific understanding than did the secondary students in their science lessons. To some extent, there were also substantial differences between Hauptschule and Gymnasium students.

But there are some restrictions that have to be considered: First, the question must be posed whether primary students have a generally more positive view on their teachers. And second, there were differences between classes on both, primary and secondary school level.

Implications

The results of the students’ perceptions of the main features of teaching for understanding (e.g., scaffolding, meaningful learning) indicate problems in secondary science instruction. In further analyses, the students’ perception will be compared to more objective analyses of instruction (video). Besides, the relationship between students’ perceptions of teaching for understanding and their gains in conceptual understanding will be studied.

References


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Altogether, these contemporary scholarly works, coming from countries around the world, are successfully displaying the current tendencies and applied methodologies in science education research that focuses on aspects of teaching.