

Part 3
Strand 3
Science teaching processes

Co-editors: Sabine Fechner & Andrée Tiberghien

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INTRODUCTION TO STRAND 3

SCIENCE TEACHING PROCESSES

As announced in the call of the conference, this strand puts together the contributions dealing with the relationships between teaching practices and student cognitive and affective development, and the design of teaching interventions. It also includes research based interventions and their role for curriculum planning, instructional paths and learning outcomes. It is noted that more specifically laboratory-based practice and also research using video analysis in science education are included.

The 16 papers included into strand 3 titled “Science teaching processes” of this eBook did not show a main tendency. Rather they cover a variety of aims, teaching processes, and methods; however they are the sign of an evolution of research in science education during these last years.

The aims are focused on (1) the teacher, their practices, their knowledge, and their perception, on (2) the students, their learning, motivation, acquisition, on (3) the instruction, its content or its structure, and on (4) the resources like the use of textbooks in classrooms in different countries. Moreover few papers are mainly focused on methodology either on the type of classroom discourse analysis adapted to the research question (Valdés-Sánchez & Espinet) or on the analyses of classroom situations at several scales (Abels).

Among these sixteen papers, it is interesting to note that only two papers are focused on a specific scientific topic, being as different as semiconductor crystals at university level (Persano-Adorno et al.) and moon phases in relation with the belief of its relationship with earth’s rotation at mainly primary level (Yamashita et al.). On the other hand, three papers deal with teaching based on inquiry, one in relation with the scientific topic of semiconductor crystals, another is focused on a pedagogical framework for primary school teachers (van Uum et al.) and the third deals with the relations between teachers’ science inquiry practices and students’ skills (Danipag). If the low number of papers on a specific topic illustrates an evolution of science education in recent years, the low number on inquiry as such may also be a sign of an evolution.

On the other hand, seven papers are focused on a specific component or resources of teaching and/or learning processes. We have the development of metacognition in relation with argumentation (Tucel et al.), the importance of sessions after laboratory work to structure knowledge (Khanfour-Armalé & le Maréchal), the role of the teacher’s technical language in chemistry on students’ learning (Tröger et al.), the role of different structures of teaching sequences (Maurer & Rincke), the development of pictorial literacy (Kobbe et al.), of meta-visual strategy in the case of using drawing and representations in electrochemistry (Locatelli & Arroio), and the importance of textbooks (Holmeier & Schaffter). Of course, these components or resources seem rather heterogeneous, however they are a sign that our knowledge of teaching processes is advanced enough to break them down into specific aspects that can be studied for their role in students’ learning.

More precisely, among these papers, some of them relate the teaching content, its organization, and the teaching resources to students’ learning and their acquisitions. One paper shows that the role of structuring the content of a lesson in a certain way is beneficial for low achievers learning, another – dealing with the use of textbooks – relates the results to the importance of developing the relationships between specific or general concepts, and

another paper emphasizes the role of precise technical language in students' learning. These papers emphasize the crucial role in students learning of how the teacher deals with the content, organizes it according to different types of classroom situations, and uses resources by taking into account the teaching duration.

Three papers are mainly focused on teachers in different ways. One deals with their perceptions about self-directed learning (Hüfner & Wilde), the two others aim at looking how to support teaching to develop students' motivation (Schneider et al.) and how to connect science and everyday life for students (Howes et al.). Another paper, which also focuses on methodology, deals with co-teaching (Valdés-Sánchez & Espinet).

On the methodology side, nine papers use classroom videos as data. For some of them, videos are the main data source, while for the other papers videos are associated with different data like interviews and questionnaires. In these last cases, more often qualitative and quantitative data treatments are used, which is also a sign of evolution of science education research.

Andrée Tiberghien¹ and Sabine Fechner²

¹ University of Lyon-CNRS, UMR ICAR, France

² University of Paderborn, Germany

FINNISH SCIENCE TEXTBOOKS: AN EXAMPLE OF BEST PRACTICE?

Monika Holmeier¹ and Heli Schaffter¹

¹ University of Applied Sciences and Arts Northwestern Switzerland, Centre for Science and Technology Education, Steinentorstrasse 30, 4051 Basel, Switzerland

Abstract: Textbooks have an important influence on what content is taught in classroom lessons and how it is taught. However, there are differences in the use of textbooks among countries which can be found in the literature (e.g., Pepin & Haggarty, 2001) and was also found within the recent tri-national Quality of Instruction in Physics (QuIP) study (Fischer, Labudde, Neumann, & Viiri, 2014). Accordingly, Finnish science teachers used the textbook in all of their lessons, whereas the textbook was nearly never used by Swiss and German science teachers.

To understand why Finnish science teachers use textbooks so often, we conducted in this study 16 qualitative interviews with pre-service teachers, science educators, textbook authors, policy-makers, science teachers and publishers. Furthermore, we coded 20 video-recorded Finnish science lessons from the QuIP study, which had already been coded during that study. The newly used coding "Use of Textbook" indicated the concrete use of textbooks in physics and was combined with the already existing coding "Organisation of classroom interaction" (Beerenwinkel & Börlin, 2014) in order to examine if the use of textbook is applicable to different classroom interactions.

The results of the video analysis in this study showed that the textbook was used in 20% of the coded sequences – mostly for the classroom interactions "Lectures" and "Discussions". Additionally, the textbook was the only teaching material used in all types of interactions and seemed, therefore, to be very applicable. The results from the interviews showed that there is a strong tradition in Finland to use textbooks and that the textbook have suitable characteristics to support teachers and students in classroom teaching and learning.

Based on our results, we discuss in this paper whether Finnish science textbooks are an example of best practice and what can be learned from Finnish science textbooks and the way it is used in Finland.

Keywords: Science Textbooks, Science Teaching, Video Analysis, Qualitative Research

INTRODUCTION

Based on Stöber's (2010) study on German textbooks, a textbook can be understood as printed learning material provided for students, which is geared to curriculum and standards, and which takes into account school and subject-specific matters, as well as the objectives, competencies and content given in the curriculum; usually it is applicable for a complete school year or school semester.

Textbooks are important for teaching and learning. According to Pepin and Haggarty (2001), they are one of the main sources for the content covered and the pedagogical styles used in classrooms. Furthermore, Heyneman (2006) described them as "instrument of extraordinary power" and as "the most effective of educational technologies invented yet" (p. 36); and therefore, suggested that close attention should be paid to the role and function of textbooks, the content given in textbooks as well as to their cost and finance for their publication. This

study draws on this suggestion and concentrates on Finnish science textbooks and their use in Finnish science classrooms.

Finnish science textbooks are hence of particular interest since it was found within the trinationa QuIP study during 2007-2014 (Fischer et al., 2014) that teachers in the video-recorded lessons of Germany and in Switzerland nearly never used a textbook. By contrast, it was clearly seen that nearly all Finnish science teachers, who were video-recorded, taught with a textbook. Due to this observation, we formulated a hypothesis that the better student performance in Finland compared to that in Germany and Switzerland, which was also found in the QuIP study (Spoden & Geller, 2014), may be linked to the use of textbooks.

In a study by Atjonen et al. (2008) on the evaluation of pedagogy in Finnish schools, it was found that only 19% of teachers used textbooks rarely or very rarely, whereas 81% use them often or very often. Workbooks were used often or very often by 50 % of the teachers. Already Kari (1988) found in his study that Finnish teachers regard textbooks or / and workbooks as a central part of their teaching work. However, both studies did not analyse why Finnish science teachers use textbooks so often. In our study, we dealt with this research gap.

Different reasons can be assumed which are stated below and are discussed from a more theoretical point of view in the next section. Finnish science teachers may use textbooks so often because:

- 1) there are differences in the culture of teaching and therefore differences in the tradition of teaching with a textbook
- 2) textbooks support teachers and student in teaching and learning
- 3) textbooks have the suitable characteristics to be used in the classroom
- 4) textbooks are applicable to typical classroom interactions

THEORY AND RESEARCH

The following sections deal with the aforementioned hypothesis. Each of the sections considers the hypothesis from a more theoretical and empirical point of view.

Use of a textbook: A matter of culture and tradition?

Already, Apple (1992) noted that textbooks are not just "delivery systems" but also "simultaneous result of political, economic, and cultural activities, battles and compromises" (p. 4). Apple's claim indicates that content, design and probably also the use of textbooks are heavily dependent on the political and social context. Haggarty and Pepin (2002) also demonstrated this for mathematics textbooks in England, Germany and France, and stated that educational traditions are reflected in textbooks and in the way they are used. They suggested therefore that the "classroom culture needs to be understood in terms of a wider cultural and systemic context, in order for shared understandings, principles and meanings to be established" (p. 588).

For Sweden, Johansson (2006) showed that the content of mathematics textbooks differs from the established curriculum, which is based on the fact that Sweden has no authorization procedure for textbooks. For Germany, Wiater (2005) determined that, for example, the use of just one specific textbook is not possible because the so-called "Kerncurriculum" is conceptualized as a very open curriculum and the teachers have to adapt the curriculum to their school realities. So working with a binding textbook would not be possible.

To sum up, if according to Kahlert (2010) the cultural self-image of a society is reflected in textbooks, then it can be assumed for Finnish science textbooks that they are influenced by educational policy decisions and traditions and that those decisions and traditions also

influence the way Finnish science textbooks are used. Horsley and Wikman (2009) gave their first indications to that assumption and concluded in their study on the role of textbooks in Finland:

Finland acknowledges the role of textbooks and teaching and learning material in student achievement and successful pedagogy. The education system of Finland enriches teacher autonomy in practice and the design of professional learning selection, modification and use of textbooks and teaching and learning resources. (p. 570)

Furthermore, according to Horsley and Wikman, the curriculum itself is not separated from its implementation. In order to support the implementation of the national curriculum, all Finnish teaching and learning materials are produced and funded according to the curriculum.

Use of a textbook: A matter of its support for teachers and students?

According to Valverde et al. (2002), "textbooks are written to serve teachers and students" (p. 10). Starting from this quote, it can be assumed that the better textbooks support teachers and students, the more often they are used for teaching and learning.

In view of textbooks as a guiding resource for lessons and a mediator between the curriculum and teacher's teaching practice (Oelkers & Reusser 2008), it seems obvious that textbooks can be supportive for teachers. Textbooks offer teachers and students a quick and easy orientation about what should be taught and learned. In addition, their use simplifies the communications between teachers who teach the same subject matter. Teachers' expectations on textbooks are primarily focused on the content of textbooks which should highly convey the curriculum. However, with the current changes in the education system, for example, the introduction of uniform educational standards, demands for more competence orientation and more possibilities of differentiation arise (Fuchs, Niehaus, & Stoltzki, 2014).

Moser Opitz (2010) also suggested that textbooks should offer more support to teachers in terms of differentiation. She recommended, for example, to divide subject matters into basal, central and additional content. Most of the teaching materials, at least with respect to Switzerland, do not provide enough possibilities for differentiation. There are, for example, hardly any textbooks for weak students because textbook authors usually have the average student in mind (Oelkers, 2010). That textbooks do not support teachers in differentiation could be a reason why the Swiss teachers rather seldom use a textbook as shown in the QuIP study. Or the other way round, the reason why Finnish teachers might use the textbook so often could be that Finnish textbooks provide several ways of differentiation or they are especially designed for weak as well as for strong students and they focus on promoting students' competences. The study of Horsley and Wikman (2009) provided evidence that the Finnish textbooks assist teacher "to develop zones of proximal development and learning environments where student learning takes place" (p. 89).

To sum up, textbooks can support teacher if they are designed according to the curriculum and to new requirements occurring within changes in the educational system or the curriculum. Textbooks should show possible solutions to current problems of concerns. Therefore, for Finland, in which comprehensive schools prevail, textbooks have to be analyzed for ways in which they support teachers in general but also in terms of differentiation and competence orientation. Their frequent use could be an indication that the Finnish textbooks have strengths there.

Use of a textbook: A matter of its characteristics?

For assuring that teachers use textbooks, they must have characteristics which make them a suitable tool for both the preparation of the lesson as well as for teaching. In this context, Ballstaedt (1997) defined three important characteristics of a good textbook: it should be functional, simple and consistent. Functionality is conducive to achieving the learning

objectives, simplicity assures reduction to essential issues and consistency assures a uniform and clear use of didactical methods.

Besides those three characteristics, language and visualization also play a central role for students. The way the text is written and the quality of the language are both of immense importance. They are both essential for student's motivation and understanding and can support the learning process (Fuchs et al., 2014). Accordingly, students have to be able to understand the text, its vocabulary and meanings. The text should guide and support the growth of knowledge and should also be based on prior knowledge of the students.

It has been discussed whether or not visual literacy needs specific competencies; and it is also an ambiguous issue if the visualization given in textbooks has to be close to reality, informative or has to stimulate students' imagination (e.g., Fuchs et al., 2014). However, nowadays more and more pictures, images, symbols and graphics are used in everyday life; therefore, it seems that visualization should be seen as a further characteristic of a suitable book. Authors and publishers should have look at good and appropriate visualizations which are consistent with the text or even foster the understanding of the text.

To sum up, functionality, simplicity and consistency, as well as high quality of language and visualization are the main characteristics of an appropriate textbook. We assume that these characteristics are well taken into account in Finnish science books which probably is one of the reasons why Finnish science teachers use textbooks so often.

Use of a textbook: A matter of its application?

In the previous section, it was shown that the quality of a textbook can be seen as one of the reasons which may influence the frequency with which teachers use textbooks. A high-quality textbook might also enable teachers to use the textbook for different kinds of teaching and learning phases in lessons as well as for doing homework (Sandfuchs, 2010). However, research shows that the use of textbooks differs in the frequency of use as well as in the way it is used.

According to Doll and Rehfinger (2012), textbooks are used for long- and short-term lesson planning as well as in the lesson itself. This is confirmed by McNaught, Tarr, and Sears (2010) who found, for example, that most of the contents in mathematics lessons are taught directly from the textbook. Pepin and Haggarty (2001) showed that in Germany, England and France, textbooks were used for three kinds of classroom activities: teaching, explaining and doing exercises, whereas teachers mainly emphasised the use of textbooks for exercises. However, only a few teachers followed the textbook page by page and the use of the textbook varied across the countries. Johansson's (2006) results in her study in Sweden are mostly concordant with those from Pepin and Haggarty. She found that teachers mostly use explanations, examples and exercises given in the textbook. However, the textbook is used differently depending on the individual teacher.

To sum up, the use of textbook differs from country to country and from teacher to teacher. However, textbooks seem mainly applicable for lesson planning, for practising with exercises and for working with examples and explanations. For Finland, we assume that Finnish science textbooks are also used for practising and introducing new topics by giving explanations and showing examples derived from the textbooks. Moreover, we assume that Finnish science teachers use the textbook for a variety of classroom interactions which can be seen as a hint that Finnish science textbooks are very applicable.

METHOD

In order to investigate the aforementioned assumptions, we conducted sixteen qualitative, guided interviews with 3 pre-service teachers, 2 science educators, 4 textbook authors, 2

policy-makers, 3 science teachers and 2 publishers. Focus of these interviews was on the following questions:

- What factors promote the use of textbooks in science lessons?
- What strengths and weaknesses do Finnish science textbooks have?

The main focus of this investigation is to gain insights into the culture of textbook usage and to determine if there is indeed a strong tradition of using textbooks in Finland. Another aim was to explore which characteristics of textbooks are mentioned by the interviewees. This should also show whether the reason for using a textbook is in the textbook itself.

Each interview lasted about 40 minutes and was transcribed and analysed using Mayring's (2004) method of content analyses, in which the interview transcripts were analysed systematically and in rule-guided ways.

Besides the interviews, twenty videos of the QuIP study (Fischer, Labudde, Neumann, & Viiri, 2014) – in which physics lessons at grade 9 in Finland were video-recorded during 2007-2014 – were re-analysed. The videos had previously been coded for "Organisation of classroom interaction" (Beerenwinkel & Börlin, 2014) which describes typical interaction forms of teaching, such as lectures by the teacher, dictation, group work, partner work and so on.

Within the re-analysis, a new coding system was developed to indicate the concrete use of textbooks in physics. For that, each video was analysed and coded in 10-second sequences. Within every sequence, the coder stated if one of the following teaching materials had been used: "Textbook", "Excerpts from other textbooks", "Textbook and Excerpts from other textbooks" and "Nothing". In order to do the new coding, the coding rules given in Table 1 were used.

A sequence was coded for "Textbook" only when the textbook, on which teacher's teaching and students' learning were usually based, was used actively, for example, if exercises were made or texts being read or copied from the textbook. In addition to using the textbook, teachers used excerpts from other textbooks such as worksheets, illustrations and so forth; this was coded as "Excerpts from other textbooks" when the material was actively used, as explained for the coding category "Textbook".

A sequence was coded for "Textbook and Excerpts from other textbooks" when both the textbook and excerpts from other textbooks were actively used. The last coding category was "Nothing", which was always used if neither the textbook nor excerpts from other textbooks were used or when teaching material which was used was developed by the individual teacher or when it remained unclear by whom the teaching material was developed.

Table 1

Coding Rules

Coding Category	Coding Rule
Textbook	<ul style="list-style-type: none"> • Used actively
Excerpts from other textbooks	<ul style="list-style-type: none"> • Used actively
Textbook & Excerpts from other textbooks	<ul style="list-style-type: none"> • Both are used actively
Nothing	<ul style="list-style-type: none"> • Neither textbook nor material from another textbook • External material developed by the teacher • Unclear who developed external material

At the beginning of the coding, two Finnish-speaking researchers double-coded 6 lessons separately to check whether the coding rules were clear and applicable. The Cohen's Kappa coefficients for the inter-rater agreement of this coupling were in the range of .80-.97, so that all other lessons were each coded by one single person. The coding was done using the software *Videograph* and the data exported to SPSS. By using descriptive analyses and cross tabulations with both variables, we used the results for determining whether the textbook was applicable for use in several lesson phases and different kinds of classroom interaction.

RESULTS DERIVED FROM THE INTERVIEWS

In the section, the results of the interviews are presented. We asked the interviewees which factors encouraged teachers to use a textbook. Their responses can be divided into five categories as shown in Table 2: "Structure", "Content", "Benefit for teachers", "Benefit for students" and "General comments".

Table 2

Reasons for using a textbook given by the interviewees

Category	Comments (Number of mentions)
Structure	<ul style="list-style-type: none"> • Logically (4) and well structured (4) • Length of lesson is regarded (2) • Books built a series → 7th to 9th grade (2)
Content	<ul style="list-style-type: none"> • Assured consideration of curriculum (8) • Manifold (2) • Well-adjusted exercises (2), different levels (3)
Benefits for teachers	<ul style="list-style-type: none"> • Guideline for planning and implementation of lessons (6) • Time saving (4) • Proven didactics and pedagogies (2) • Helpful for longer absence of teacher (4) • Generally important support (5)
Benefits for students	<ul style="list-style-type: none"> • Good visualisation (5) • Suitable language (5) and level (2) • Textbook sets minimum level (5) • Equal treatment of all students (4) • Helps after long absences (2) • Generally important support (4)
General comments	<ul style="list-style-type: none"> • Parents think textbooks are important (3) • Strong tradition in Finland (3)

The interviewees said the textbook is used as it is logically set up and well-structured. It is set up in a way in which the length of the lessons is considered. Furthermore, textbooks are conceptualized as a series and can therefore be used for subsequent grades.

Besides the structure, the interviewees also mentioned factors related to the content of textbooks. In the opinion of the interviewees, textbooks are used so often because the textbooks highly reflect the curriculum. Dealing with the topics given in the textbooks therefore assures that all relevant topics mentioned in the curriculum are taught in the lessons. The topics are also very manifold and there are many well-adjusted exercises given in the textbooks which take into account different attainment levels of the students.

Using a textbook does provide benefits for the teacher. Textbooks are seen as a good guideline for planning and implementing the lessons. From the interviewees' point of view, it is time saving to work with textbooks, which are especially helpful when the teacher might be absent for a longer time. Teaching with a textbook is easier for the substitute teacher who knows which topics are to be dealt with in teaching. Teachers are also supported by textbooks due to the proven didactics and pedagogics on which the textbooks are based. Therefore, teachers do not have to develop something completely new in their teaching.

Besides the benefits for teachers, benefits for students were also mentioned during the interviews. Textbooks support student learning. On the one hand, textbooks offer good visualisation, suitable language and an appropriate level of requirements. On the other hand, textbooks also set minimum standard for student learning. These requirements are the same for all students and valid to everyone. In this way, none of the students is being disadvantaged. This also encourages the students by giving them certainty, especially for weak students as they know what they should be able to do and know at least. The textbook is helpful to the students when they are absent for a longer time in a similar way as it is helpful the teachers who are absent, because they always know what they have missed and so they are able to catch up with the topics in the textbook.

Generally, most interviewees said that the textbook is used because the parents find its use important and because there is a strong tradition to work with the textbook in classroom teaching and learning in Finland.

RESULTS DERIVED FROM THE VIDEO ANALYSIS

The analysis of the QuIP video-data showed that in 20% of the coded sequences the textbook was used. Besides this general outcome, three specific results were also revealed.

Firstly, all of the four different teaching materials were used mainly for another kind of classroom interaction (see Table 3). Whereas the textbook was mostly used for "Lectures" (24.4%) and "Discussions" (24.5%), "Textbook and Excerpts from other textbooks" were mostly used for "Group work" (47.1%). "Excerpts from other textbooks", however, were mostly used for "Individual work" (29.4) and "Discussions" (26.7) while "Nothing" was mostly coded for "Lectures" (30.4) and "Discussions" (29.4).

Table 3

Frequencies of classroom interactions in which different materials are used

	Textbook	Textbook & Excerpts from other textbooks	Excerpts from other textbooks	Nothing
Lectures	24.4	8.2	22.9	30.4
Dictation	3.1	14.8	5.5	11.2
Discussion	24.5	10.9	26.7	29.4
Individual work	7.7	9.1	29.4	2.6
Partner work	2.9	--	--	--
Group work	4.3	47.1	--	4.6
Several kinds of interactions	16.4	--	--	7.1
Transition	14.6	10.0	13.5	14.6
Others	2.1	8.2	2.0	0.1

Secondly, the textbook is the only material which is used in every work mode. So for example none of the other teaching materials is used during "Partner work". Furthermore, "Excerpts from other textbooks" was never coded during "Group work" and during "Several kinds of interactions".

Thirdly, "Textbook and Excerpts from other textbooks" is more frequently coded in combination with "Group work" than with any other work modes. In nearly half of the sequences in which "Textbook and Excerpts from other textbooks" was coded, "Group work" was also coded. It will be discussed in the following section what this result may mean.

DISCUSSION AND CONCLUSIONS

Looking back to our assumptions, we found a clear hint that there is a strong tradition for teachers in Finland to use textbooks. The interviewees not only mentioned that there is a strong tradition but also that the parents think that textbooks are vital. This might be due to the fact that the parents' lessons were also taught according to a textbook. If so, this would even more clearly confirm the hypothesis that there is a strong tradition in Finland in using a textbook. Actually, when we told Finnish policy makers and teachers that we are interested in their science textbook and why they use it, they were each time very surprised. This is because, for them, it is not a question of why the textbook is used, but why the textbook should not be used when it is there. Their reactions also showed how common it is to use textbooks in lessons in Finland.

We also found according to our second assumption that the textbook is very supportive for students and teachers. The main support is that the teachers using the textbook are relieved in their everyday work. On the one hand, the textbook shows the teachers where to go and offers the certainty in implementing the lesson. On the other hand, the textbook forms a unit regarding the length of each of the lessons, which offers certainty in planning as well. Additionally, the textbook is based on proven and actualized didactics and suggestions for teaching in a lesson, so the teacher does not have to come up with his/her own ideas.

The textbook is also supportive for the students. On the one hand, they are guaranteed that the topics of the curriculum are dealt with; and therefore, they receive education of high quality. On the other hand, they feel equally treated in classroom teaching as the minimum requirements and topics are not dependent on the teacher but are set by the textbook. Furthermore, the textbook is motivating because it is handy, having a good layout and written in clear, intelligible language.

Our third assumption that textbooks are used due to their suitable characteristics was rather clearly confirmed in this study. From the interviewees' point of view, the textbooks are well structured and the contents are manifold and reflect the curriculum well. The statements given in the interviews can also be confirmed by our analysis of different science textbooks in which we found a suitable language and an appropriate way of illustrating the content.

Within the video analysis, we were able to confirm our fourth assumption that the textbook is applicable for different kinds of classroom interactions. This can be seen in the fact that it is the only teaching material which is used for all of the several kinds of interactions. In particular, the textbook is often used when the teacher is imparting new knowledge or contents in a lecture; this shows how important it is for the textbook to reflect the curriculum. Another reason why textbook should be developed regarding the curriculum is that we found that the teachers base their lessons in most parts on the textbook. If they use excerpts from other textbooks, it is only to present contents of the textbook in a different way or to complement it.

Another interesting result was that textbook and external materials are more frequently used in combination with group work than with other work modes. This shows that whenever teachers have to use teaching materials to suit more than one student's needs and to offer a wider choice of exercises – which happens mainly during "Group work" – more teaching material than just the textbook is needed. Furthermore, it also shows that teachers seem to think about which teaching material works best in which kinds of interactions. Otherwise, all different teaching materials would have been used in the same way and there would not have been such clear results in this study that nearly 50% of "Textbook and Excerpts from other textbooks" are used for group work.

An Example of best practice?

Our paper deals with the questions if Finnish science textbooks can work as an example of best practice. Given our results, we can on the one hand answer in the affirmative. Finnish science textbooks have suitable characteristics as those demanded in the literature. They are written in a clear way, with good visualization, and they are consistent and rather simple as they are aligned to minimum standards in order to help student to see what they have to learn at least. Furthermore, Finnish science textbooks seem suitable for different classroom interactions. So the way they are designed can be seen as an example of best practice. Moreover, there is not the slightest doubt that teachers in Finland should use a textbook. Using a textbook is strongly anchored in the Finnish school tradition and this way of using a textbook as well as this strong conviction can also be regarded as an example of best practice.

On the other hand, there are also some critical statements given during the interviews which slightly negate the claim of using the textbook as best practice. As the textbook is such supportive for teachers, there might be the risk that teachers blindly follow the textbook – which then leads to the case that teachers show no self-motivation in developing new ways of teaching. Some interviewees also criticize that students are not encouraged to be self-reliant in their thinking. Some teachers also mentioned that visualisation in the textbook is not always adequate, rather too fanciful or that there are just too many illustrations. Furthermore, it was criticized that the textbook contains some mistakes and has highly simplified explanations. It was also complained that there are sometimes too many references to everyday life so that scientific theories lack attention. Interviewees' single statements were that in total the price for the textbook is considered to be too high, especially because there are quite often new editions. Therefore, students in the following years are not able to work with the same textbook and schools always have to buy new textbooks for the students even though there were only small changes in their new editions (e.g., changes in exercises or graphics).

Related to these criticisms, the interviewees also gave some recommendations that could help Finnish science textbooks to really become an example of best practice. Referring to the contents, many interviewees wished that the textbooks should have more interdisciplinary topics and topics which enable teaching in lessons across the grades, for example, topics about climate change, energy or nanoscience. It was also mentioned that there should be generally new challenges in the textbooks, for example, integration of new media. Many of the interviewees would prefer new textbooks that target different groups of students, for example, textbooks for students learning Finnish as a second language, or textbooks for gifted students. In response to the criticisms that self-reliant thinking of the students was not encouraged in the textbooks, some interviewees wished that more emphasis be placed on that kind of thinking. Therefore, the textbooks should contain more experiments, more problem-solving exercises and generally more references to everyday life. There should be more variations in the work modes and possibilities for group work. Only one interviewee suggested that the focus of the experiments in textbooks should be more on the process of experiments, rather than on their results.

Practical Implications

The study shows that Finnish science textbooks and the way they are used have the potential to become an example of best practice. It can be seen that it is important that textbooks highly correspond to the curriculum so that teachers and students are always certain that they teach and learn what has to be taught or learned.

It seems necessary to define minimum standards which are also regarded in the textbook so that each student knows what he or she has to understand at least. This could be motivating for weak students because they know that they will probably pass an exam by knowing what is given in the textbook. However, also strong students should be regarded which means that textbooks should contain sufficient tasks and experiments for students at all achievement levels.

From the results we can also see that Finnish science books are applicable for different classroom interactions which may be a reason why it is used so often. Therefore, textbook authors should not only pay attention to the content and the way the content is presented in textbooks, but they should also consider possibilities to make textbooks applicable. So, for example, textbook authors could suggest how teachers can use the textbooks or suggest concrete examples for group work or inquiry-based learning in which students are supported by the textbooks.

In addition, it seems important that teachers feel supported by the textbooks. This can be realized by giving them concrete suggestions for teaching with the textbooks, by developing a textbook which highly corresponds to the curriculum (as mentioned above) and which contains exercises for students at different attainment levels and exercises which can be done easily during a lesson. Furthermore, it seems important that topics in the textbooks can be split into units of lessons, as it happens in Finland.

Last but not least, it was very important for the entire group of interviewed people to emphasize that teachers should have the freedom of choice in whether they want to use a textbook and which one they want to use. In Finland, this seems to be working as all interviewed teachers use a textbook without being obliged. But, it seems important that teachers should reflect on their own decision of using or not using a textbook and the reason for such decision. Publishers and authors can learn from teachers' reasons and can probably adapt their textbooks to their needs.

Limitations

With the results of our study, we are able to get a short insight into the Finnish science textbooks and their use. However, there are some limitations of our research. The analysed videos did not focus on the use of textbooks and therefore important data was not included. New recordings are required so that they really focus on the use of the textbooks.

Additionally, it is necessary to get more insights into teachers' use of a textbook during their lesson preparation and so there should be studies which video-record teachers in their preparation phase and then collect more data from them by interviews or questionnaires.

Besides teachers' use of textbooks, it is also important to analyse students' use of textbooks and how they benefit from them. Indeed, the interviewees talked about students' benefits. However, it would be interesting to know how the students themselves think about the benefits of using textbooks and their experience with the way their teachers work with textbooks. Furthermore, to complement the use of traditional textbooks, new media should also be considered; this was not taken into account in this study but should be in future studies. Finally, replication of this study in other countries would be interesting in order to see to which extent and for what reasons textbooks are used or not used there.

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KNOWLEDGE ACHIEVEMENT OF DIFFERENTLY STRUCTURED LEARNING SEQUENCES

Christian Maurer¹ and Karsten Rincke²

¹ University of Regensburg

² University of Regensburg

Abstract:

One of the main quality criteria of effective lessons is a well-structured and organized learning sequence. To design such a sequence different guidelines or theories exist. The effects of two guidelines (theory of basis-models and the inquiring-developing procedure) on knowledge achievement were investigated. For this investigation two 90-minute lessons were developed, each according to one of the guidelines. Both lessons had the same content (introduction of momentum) and used the same teaching methods and the same media. The study was designed as an exploratory quasi-experimental laboratory setting. The sample consisted of 796 pupils out of 32 classes (10th grade) of secondary schools in Germany. A knowledge test was held before (pretest) and after (post-test) the lessons to measure achievement. Additionally, many organisational variables and partly the cognitive basic skills were controlled for. Each method which was used to analyze the data (t-Test, ANCOVA, multilevel analysis) shows a highly significant difference on knowledge achievement between the two intervention groups. The basis-model-group has a significantly higher group-mean-score in the post-test with a small to medium effect size. The size of this impact differs, if groups of students with a high or low level of prior knowledge are considered. The lesson given according to the theory of basis-models was especially beneficial for pupils lacking prior knowledge, but didn't disadvantage those who scored high in the pretest. Previous research studies regarding the theory of basis-models showed similar results concerning the impact on learning. In one of these studies even the impact's dependency on the student's level of prior knowledge was shown. In combination with these studies, the theory of basis-models seems to be a promising theoretical model for designing (physics) instruction regarding achievement and may help to avoid mental overload as it particularly fosters those who lack prior knowledge.

Keywords:

Instructional Design, Science Teaching Processes, Learning Sequences

THEORETICAL FRAMEWORK

The term “structure”

In the context of teaching the term *structure* can have different meanings. Lipowsky (2009) highlights a cognitive-psychological, a behavioral and a didactical facet of what could be meant by 'structure'. The first facet of structure is fulfilled, if lessons contain actions which activate and connect prior knowledge or build up a systematic knowledge structure (e.g. advance organizer or concept mapping). The structure out of a behavioral point of view represents the second facet. From this point of view, a good structure means that disciplinary aspects are considered and the student's actions in the classroom are based on rules or norms

(classroom management). The third facet is called didactical structure. It can be operationalised in a systematic stepwise construction of a lesson's content or a discernible and appropriate division of a lesson in single phases (e.g. mastery learning or Direct Instruction). The latter aspect of the didactical structure of a lesson represents the general understanding of the term *structure* for this article.

The relevance of a lesson's structure

One of the main quality criteria for knowledge achievement is the question to what extent a lesson is well structured (e.g. Brophy 2000; Helmke, 2009). Especially pupils lacking prior knowledge benefit from a well structured lesson (Helmke, 2009). Elements of the didactical structure (Direct Instruction, inquiry based teaching or problem-based learning) are assigned in Hattie's meta-meta-analysis (Hattie, 2009, p. 200ff) with a positive impact on learning, but each on a different level. Their average impact described by Cohen's d reaches from 0.15 (problem-based learning) to 0.59 (Direct Instruction). The elements themselves differ in their impact on learning, depending on subject contents, the subjects themselves, or different learning goals. For example, problem-based learning can have negative effects on building up surface knowledge, but seems to work quite well if the lesson is intended to foster deeper understanding or application of the subject matter and the surface knowledge is already available (Hattie, 2009, p. 211). Overall there is no generally accepted ideal way to structure a lesson. Even if goal, subject and content of a specific lesson are given, there is no validated advice, which instructional sequence should be chosen. However, different theoretical models for sequencing instruction depending on the specific goal (and partly on subject content) of a lesson do exist. But again, the question which of these models is to be chosen cannot be answered yet.

Models for sequencing instruction

This study is based upon two models, the so called *Forschend-entwickelndes Unterrichtsverfahren (FeU; engl.: inquiring-developing procedure)* (Schmidkunz & Lindemann 1992) which is a model developed with respect to science education, whereas the *theory of basis-models (BMT; dt.: Basismodelltheorie)* (Oser & Baeriswyl, 2001) as second model for sequencing instruction is expected to work for all subjects.

Within the framework of this study, we used a modification of the *theory of basis-models* with respect to for physics education by Reyer (2004) and Wackermann (2008 and 2012). In a pursuing field-study referring to Reyer and Wackermann, Zander (2013) observed a significantly higher learning gain ($d = 0.32$) for students in a BMT-group than in a comparison group. This effect was strongest on students scoring low in the pretest held (Zander, 2015). Previous studies on the modification and the basic form of the BMT showed positive effects as well. These effects were shown to be mainly in terms of cognitive aspects (e.g. Wagner, 1999; Ohle 2011). A comparison of the impact of the BMT with another model is missing. This is the main concern of this article.

The effects on learning outcomes of the FeU have not yet been under the scope of research studies, but the FeU is nevertheless an important standard model in German science education, in classrooms as well as in teacher training programs (DiFuccia and Ralle, 2010). It is well known and often used.

Both the BMT and the FeU vary in their proclaimed learning sequence depending on the underlying conditions to suit a wide range of topics and purposes.

The FeU therefore distinguishes two kinds of problem situations. Situations in which the students already have the required knowledge but lack the way to solve the problem (deductive path) and situations in which phenomena are presented and the students lack the required knowledge to explain their observations (inductive path). The deductive path is

similar to Problem-based Learning, whereas the inductive way combines elements of Inquiry Learning, Problem-based Learning and Discovery Learning.

In the modified version by Wackermann (2012), the BMT distinguishes four different types of learning and therefore four differently structured learning sequences: Learning through experience, conceptual change, problem solving and concept building. The theoretical framework of the BMT also has many features in common with other existing guidelines, including Direct Instruction, but is not a combination of different guidelines into one. It rather gives advice which of these different guidelines suites best for designing a specific lesson, whereby this advice is given on the basis of the lesson's learning goal.

STATEMENT OF INTENTION

The FeU and the BMT both offer well documented and comparably strong structured guidelines to sequence a lesson, and claim to give an ideal guideline for designing a learning sequence in terms of learning outcomes. Additionally, both models are not demanding any specific teaching methods during the lesson (Oser & Baeriswyl 2001, Schmidkunz & Lindemann 1992), which enables us to design the intervention lessons aiming at the comparison of the guidelines in terms of learning outcomes and not testing for effects of different teaching methods. The question, whether a specific lesson is best structured according to the FeU or the BMT or another model, cannot be answered yet. The intention of this study is to investigate, whether lessons show a different impact on achievement when based on the guidelines of either the FeU or the BMT.

Research Questions:

- Do different learning sequences lead to a different achievement in content knowledge when designed accordingly to different theoretical models?
- Do different groups of the sample benefit in a different way from the intervention?
- What aspects of the instructional sequences may be responsible for the potentially different learning outcome?

This study is not expected to fully explain differences, but might suggest possible reasons.

METHOD

Design of the study and the intervention lessons

The study is designed as an exploratory quasi-experimental laboratory setting. Previous field studies indicate that the quality of lessons strongly depends on how accurately the theoretical guidelines are realized and that lessons designed by teachers often lack this accuracy (Reyer 2004, Wackermann 2008). The study was designed as a laboratory setting in order to provide comparable circumstances and to ensure that the guidelines of the tested models were fulfilled. As the theoretical framework of this study does not allow generating testable hypotheses regarding the research questions, this study has an exploratory character. Finally, this study is quasi-experimental simply due to pragmatic reasons. For our laboratory study one teacher (at the same time being the investigator) and one room at our university were available. In order to maximize the number of classes visiting the university in order to attend a lesson and therefore the sample size, we wanted the organization by the teachers to be as easy and the necessary time for a visit to be as short as possible. So we did not randomly split visiting classes and inevitably force parts of the classes to wait.

To compare the effects of the different sequences, specially designed lessons were given in a classroom-laboratory at the University of Regensburg. According to the guidelines of the FeU

and the BMT respectively (the adapted version for physics education), two 90-minute lessons were developed. Both lessons had the same content (introduction of momentum) and used the same teaching methods and the same media. An external validation confirmed these similarities and even stated that some parts of the learning sequences in both lessons are nearly identical (Hahn, 2014). At a superficial level the differences between these two lessons are not really apparent. But taking a deeper look into the internal structure differences emerge. In the lesson designed according to the guidelines of the BMT, parts of the content were generalized out of the experimental results during the lesson and further information was presented. The new content or concept gathered in this way was applied in various contexts. One main goal of the application phase was to practice the new content or concept and an additional phase of interlinking (connections between physics concepts) was included.

In contrast, in the FeU-lesson pupils were expected to discover parts of the content in the experimental results. Further information was abstracted from these results. So every bit of new information was derived from the experiments conducted. The main goal of the FeU-application phase was crosslinking new contents to different subjects, sports or other aspects of everyday life and not primarily practicing the usage of the new learnt content. These differences between the intervention lessons might cause possible differences in the learning outcome.

Data acquisition

This learning outcome was measured using a knowledge test (22 Items; split-half reliability of 0.72) before (pretest) and after (post-test) the lessons. Additionally further confounding variables were controlled for. These variables embody organizational aspects like sex and class type (focus on science or not) of the participants, the class sizes as well as length or starting time of the lessons. In the first part of the study, we tried to control the student's competence in experimental knowledge construction, but didn't achieve an acceptable reliability ($r = 0.52$, $N = 291$) and therefore stopped measuring. Afterwards we implemented a short-test (11 Items; $r = 0.65$, $N=505$) of the subtest N2 of the KFT (Hellmann & Perleth, 2000) to measure the student's cognitive basic skills and consider their impact on learning in our analyses.

In order to examine whether the behavior of the teacher (investigator) unconsciously differed between the intervention groups (Rosenthal Effect; quoted from Bortz & Döring, 2006, p. 84), the students assessed the level of the perceived "interest" (3 Items, $r = 0.63$) and of the "motivational support" (6 Items, $r = 0.65$) by the teacher. The summary scale "teacher perception" with 9 Items, reaches a reliability of $r = 0.75$.

Sample

The sample consists of 796 students from 32 classes of the 10th grade of German secondary schools. Regarding overall size, average size of class, class type, gender, cognitive basic skills, length and starting time of the lessons, there were no significant differences between the two intervention groups.

Analysis methods

Differences within the intervention groups as well as differences between the groups (without considering the confounding variables) were analyzed via paired (within, effect size: partial eta-squared) or classical t-tests (between, effect size: Cohen's d). To control for the confounding variables, we ran multi-factorial ANCOVAs with the post-test score as dependent variable and the pretest score as additional control variable besides the above mentioned confounding variables. The effect size type was set as Omega squared ω^2 . These ANCOVAs were mostly used for analyses concerning special parts of the whole sample. With the total sample (796 students out of 32 classes) we ran a multilevel analysis in order to take

the substantial hierarchical data structure ($ICC1 = 0.14$) into account. Depending on the type of the underlying variables (dichotomous or continuous), we calculated the effect sizes for the multilevel analysis according to Tymms (2004). These effect sizes can be compared with Cohen's d used for the classical t-tests. To prove, if the pretest score has a significant moderator effect on the effect of the intervention, a test procedure in terms of Frazier (2004) was conducted.

RESULTS

Regarding the teacher's perceived behavior neither the summary scale "teacher perception" nor the part scales "interest" or "motivational support" did show any significant differences in the evaluation by the students between the intervention groups. This means that there was no indication of a systematic Rosenthal Effect.

As figure 1 indicates, no systematic differences were found between the pretest scores of students out of the FeU or the BMT-group. Significant differences did show, when pretest score and post-test score within both the FeU-group ($t(390) = 16.7, p < 0.001$) and the BMT-group ($t(404) = 21.6, p < 0.001$) were compared. In both groups a systematic learning gain was measured (see figure 1). Additionally the gathered data showed a highly significant difference in knowledge achievement (difference between pre and post-test scores) between the intervention groups ($t(794) = -4.29, p < 0.001$). The size of the effect is small $d = -0.30$ (see also figure 1).

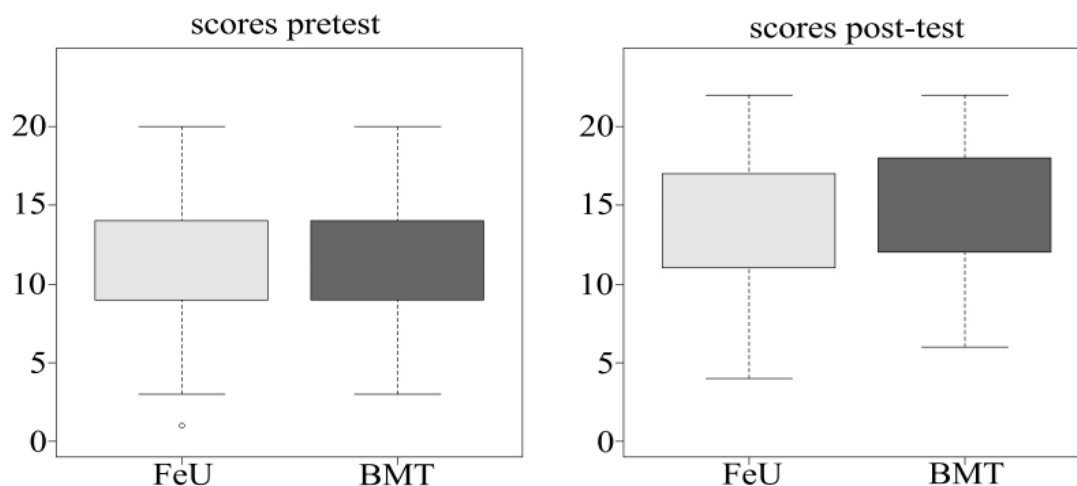


Figure 1: Boxplot of the student's results in the knowledge test before and after intervention.

The lesson according to the guidelines of the BMT led to a significant and relevant higher learning gain in the chosen context of linear momentum. To consider the possible impact of the confounding variables in our analyses, we conducted an ANCOVA for the whole sample, including those variables and the pretest scores as additional predictor for the depending variable (post-test score). The results of the corresponding ANCOVA are shown in table 1.

The pretest score was proven (highly significant) to have the strongest effect (with a large effect size) on the post-test scores. High pretest scores were connected with high post-test scores. The corresponding effect size differed between the two intervention groups. In the FeU group ($N = 391$) the effect size of the pretest score was $\omega^2 = 0.333$ whereas in the BMT group ($N = 405$) it was $\omega^2 = 0.190$, still being the strongest influence in this part of the sample. When looking at gender, this variable turned out to be a small but again highly significant effect, whereby the male participants scored higher in pre and post-test and had a higher learning gain. The starting time of the lesson also represents a highly significant effect

with a small effect size on the post-test scores. Higher scores were achieved when the lessons started earlier. Both effects gender and starting time didn't differ in their effect size between the intervention groups. In accordance with the results of the t-tests, the type of lesson (lesson according to BMT or FeU) is a highly significant and small effect on the post-test scores favoring BMT. This effect didn't change in significance, size or direction, when the cognitive basic skills (KFT) were controlled for in an ANCOVA of that part of the sample where students were tested using the KFT. No effects were caused by the duration of the lessons, the class size or type.

Table 1: ANCOVA test: Effects on achievement (post-test); N=796

	F -value	p-value	Effect size ω^2
Pretest	275.89	0.000***	0.257
Gender	33.38	0.000***	0.039
Starting time of lesson	23.29	0.000***	0.027
Type of lesson	19.87	0.000***	0.023
Duration of lesson	0.60	0.440	--
Class size	1.76	0.185	--
Class type	0.36	0.550	--
Signif. codes:	**** 0.001	*** 0.01	** 0.05 . 0.1
Effect size ω^2 :	small: 0.01	medium: 0.06	large: 0.14

Nevertheless, the class structure had a systematic and substantial impact on the depending variable. This was indicated by an ICC of 0.14. This means 14% of the total variance in the post-test scores can be explained by differences between classes. In order to take this into account in our analyses we ran a multilevel analysis of the total sample. Most of the variables of the ANCOVA were also used in the multilevel calculations. Only the variables without effect on the post-test score were not integrated in our calculations, because the quality criteria (AIC and BIC) indicated a better multilevel model without these variables.

The results of the corresponding multilevel analysis are shown in table 2:

Table 2: Multilevel analysis: Effects on achievement (post-test); N=796

	value	DF	t -value	p-value	Effect size d
(Intercept)	9.50	762	17.3	0.000***	---
Pretest	0.54	762	16.4	0.000***	1.24
Gender	-1.40	762	-5.77	0.000***	-0.48
Starting time of lesson	-0.40	29	-3.50	0.002**	-0.38
Type of lesson	0.93	29	2.90	0.007**	0.32
Signif. codes:	**** 0.001	*** 0.01	** 0.05	. 0.1	
Effect size d:	small: 0.20	medium: 0.50	large: 0.80		

Basically, the results both of the ANCOVA and the multilevel analysis of the whole sample are comparable regarding significance and effect size for the considered variables (gender was coded 0: male and 1: female; type of lesson was coded 0: FeU and 1: BMT).

Therefore the BMT-Intervention led to a significantly higher gain in learning independent of the method of analysis. This intervention effect depended systematically upon the pretest score level of the participating pupils. This means the pretest score is a significant moderator of the intervention effect. In order to visualize this, we formed (ex post) four groups of students (G1 to G4) depending on the student's score in the pretest (see also Figure 2a). Figure 2b shows the pretest score dependency of the intervention effect.

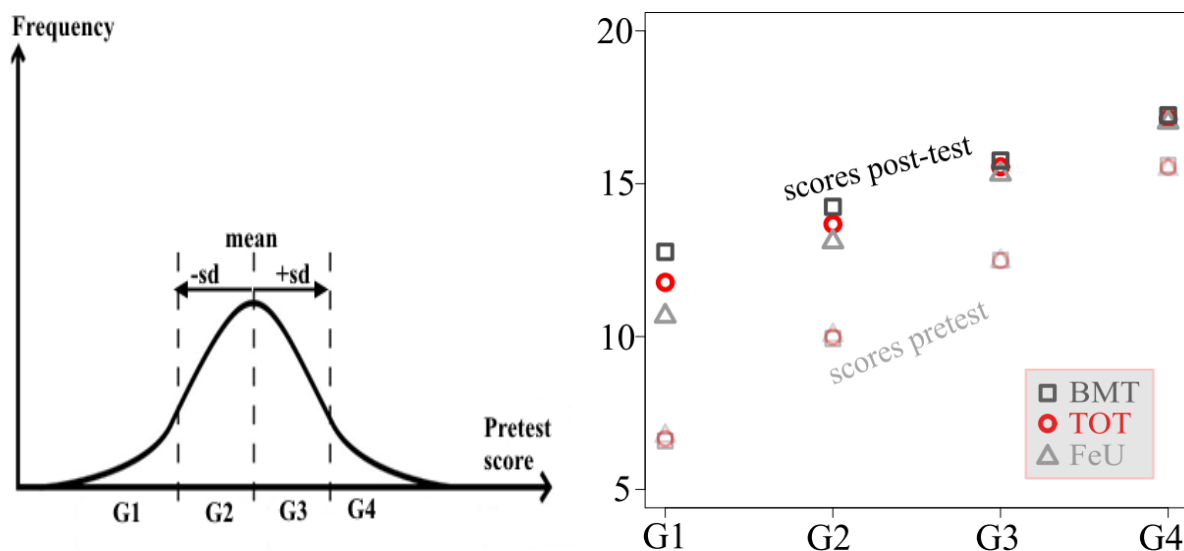


Figure 2a: left: The figure illustrates how the groups were built to visualize the moderator effect.

Figure 2b: right: Mean scores in pre (partially transparent) and post-test of students in the groups G1 (low pretest score) to G4 (high pretest score). TOT represents the data of the whole sample, BMT and FeU the data of students being part of either the FeU or the BMT group.

Participants with a low level pretest (G1; $N = 158$) benefited more (indicated by the difference between FeU and BMT students in the post-test) than students with higher pretest score. So the lesson designed according to the guidelines of the BMT was especially beneficial for pupils lacking prior knowledge. There were no disadvantage for students with a high prior knowledge (G4; $N = 221$).

DISCUSSION

As mentioned above, both types of lessons show several similarities, e.g. teacher behavior, content, media and teaching methods. Even some parts of their learning sequence are nearly identical. With regard to these similarities, the above reported differences must be caused by these details. So details of the structure of a learning sequence seem to have a substantial impact on the quality of teaching.

An important detail that differed between the two intervention lessons was the additional interlinking phase in the BMT-lesson. Connections between physics concepts recently were shown to correlate positively (medium size of correlation) with the average learning gain in a

study by Helaakoski and Viiri (2014). Their study was part of the QuIP-Project (Quality of instruction in Physics), which compared Finnish, German and Swiss lessons. In accordance with the results of Helaakoski and Viiri, the study reported in this paper as well indicates that interlinking phases in physics education seem to be a promising approach, at least regarding achievement.

Apart from interlinking, further differences in the given lessons can be found. Practicing the new built concept is a primary goal in the larger part of the application phase of the BMT-lesson, whereas the FeU-lesson's application phase mainly focused on searching for crosslinking connections. This may be difficult and hinder a better understanding, because this way some pupils might search for connections before they practiced the new content thoroughly enough.

Additional abstraction of further information out of the experiments can only be found in the FeU-lesson. This abstraction requires an extra cognitive endeavor, because several steps of the abstraction contained elements of prior knowledge. In the BMT-lesson further information simply is presented. This could mean that the FeU-lesson maybe placed too heavy demands on some of the students. These demands may cause the diminished learning gain of FeU-students compared to those of BMT-students, since the differences in achievement are especially noticeable on students lacking prior knowledge. Maybe those students lacking prior knowledge suffer most from high mental demands.

The study was designed to reveal differences in achievement as long as those differences exist. The study is not expected to explain their reasons, but it may indicate possible reasons. Three possible reasons (the main differences in the given lessons) are listed. Each possible reason may have an impact on student's achievement, but to identify those single effects further studies are required. In addition, further studies could investigate if a variation in the design of the study, like the chosen subject, the content learnt or the type of study (e.g. field study), causes differences in the results. Regarding other results of studies concerning the BMT, generalizations are still hard to make, but these studies do share some findings.

The BMT lessons in Zander's study also were particularly suitable for students with a low level of prior knowledge. So the results of Zander's study and the results of the study reported in this paper both place emphasis on the BMT being especially beneficial for students with a low level of prior knowledge.

Several studies on the BMT had shown, that lessons according to the guidelines of the BMT have a greater impact on learning in primary (Ohle, 2011) and secondary (Draxler, 2005; Zander, 2013; this study) physics lessons as well as in other subjects (Wagner, 1999), than the group compared in each study. Taking these results into account, the BMT (especially the modified Version for physics education) seems to be a promising theoretical model for designing (physics) instruction, regarding achievement.

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CONTRIBUTIONS AND LIMITATIONS OF A METAVISUAL STRATEGY FROM THE PERSPECTIVE OF STUDENTS

Solange W. Locatelli and Agnaldo Arroio

Faculty of Education – University of Sao Paulo – Brazil

Abstract: The purpose of this research was to identify the opportunities and limitations of this strategy in the perception of students. The idea was that the strategy could enable modeling concepts. For this, the approach was to compare the assumptions on drawings made by students, with an image containing a representation submitted by the researcher, to study two chemical interactions with exchange of electrons. In this context, a metavisual strategy was conducted with 28 high school students to learn initial concepts in electrochemistry. Students were arranged in pairs and the duration of this task was approximately 100 minutes. The interactions analyzed were from steel wool and an aqueous solution of copper sulfate and steel wool and an aqueous solution of sulfuric acid. This teaching and learning sequence (TLS) was videotaped, transcribed and analyzed. The data indicate that the metavisual strategy may have been efficient in the reconstruction of ideas, as it was reported by 85.7% of students. It can also be highlighted here the importance of the teacher's role as a mediator, since 57.1% of these students needed his help to properly understand the concepts of electrochemistry. Finally, research indicates that more studies are necessary to understand and minimize the factors which contribute to the limitations of the strategy.

Keywords: instructional strategies, metacognition, science education.

INTRODUCTION

Many different and creative strategies have been used in science teaching, thereby it is important to know their contributions and limitations, in order to have the opportunity to improve their use. Models are in the public arena by means of a series of modes of representation, visualization being a central element in learning science (Gilbert, 2005). According to Rapp & Kurby (2008), external visualizations (figures, graphics, etc.) allow students opportunities to build mental models and Schnotz & Kurschner (2008) point out that this construction can be affected by the way they arrive at the apprentice. Wu & Shah (2004) indicate that many conceptual errors occur, since the students are not able to understand these representations. Locatelli & Arroio (2014) suggest some factors that may contribute to these errors, such as the lack of theoretical reference, the difficult understanding of submicroscopic universe and their previous ideas, which are strong. The metacognitive learner is characterized by being able to recognize, evaluate and even rebuild previous ideas (Noushad, 2008), also encompassing the ability to reflect and redirect their own thinking and learning (Ambrose & Lovett, 2014), controlling and understanding their own thinking (Sternberg, 2000). Consequently, it is essential to become metacognitive regarding the visualization, metavisualization, in other words, students should develop the metavisual capability (Gilbert, 2005). According to Locatelli & Arroio (2015) metavisualization involves the interpretation of external visualizations by the students all the time, since scientists use models for understanding the chemical principles. Moreover, if more external representations are available to it, the learner may have greater opportunity to construct an appropriate mental model to the understanding of a concept (Schnotz & Kurschner, 2008). Finally, it is worth noting the

important mediating role of the teacher in the acquisition of knowledge (Locatelli & Arroio, Metavisual strategy assisting the learning of initial concepts of electrochemistry, 2014). Regarding to electrochemistry, some errors are common and this strategy may enable the externalization of them and consequent correct reconstruction of the concepts from the scientific point of view. Rosenthal & Sanger (2012) state that students have difficulty in learning this topic, for example, they fail to recognize that the particles may change in size, if there is a loss of electrons in the process, among other misconceptions. This study aimed to investigate with the students, what are the contributions and limitations of the metavisual strategy to learn early concepts in electrochemistry.

METHOD

A teaching and learning sequence (TLS) involving a metavisual strategy was proposed to a group of 28 high school students, volunteers, organized in pairs, aged 16 and 17, in order to introduce the initial concept of redox reaction. The duration of the task was about 100 minutes in the classroom.

Students were videotaped while performing and the speeches transcribed for later analysis. Finally, at the end of the TLS, students answered a questionnaire, arguing about the opportunities and the difficulties they had during the activity.

Five categories were created from the analysis of the reports of the students, see table 1:

Table 1. Five categories - opportunities and difficulties provided by metavisual strategy.

Opportunities	Difficulties (limitations)
I. Recognition of differences in particle size.	IV. Comprehension the transfer of electrons was not possible.
II. Observe difference/ make self-regulation/ ratify.	V. Partial comprehension of the representation of balls
III. Comprehension how interactions happen.	

TEACHING AND LEARNING SEQUENCE (TLS)

First, they studied the chemical interaction between the steel wool and an aqueous solution of copper sulfate. Students were asked to predict what they thought would happen in this interaction. Following, they observed the chemical reaction and proposed hypotheses to explain what they were watching. Explanatory models on the symbolic level (chemical equation) and submicro (drawings containing particles) were asked to students to represent the initial and end states of the interaction, an example done by the students was given below (figure 1).

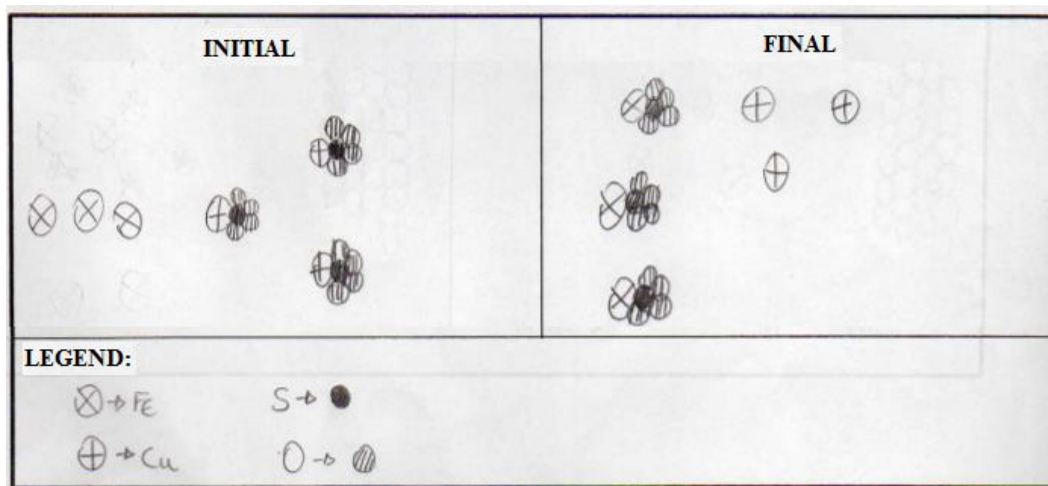


Figure 1. Representation of particle interaction, made by a pair of students – First interaction.

Once they finished preparing their hypotheses, they had to compare with a representation that was presented by the researcher (Figure 2), looking for similarities and differences, trying to correct or ratify their proposed hypothesis.

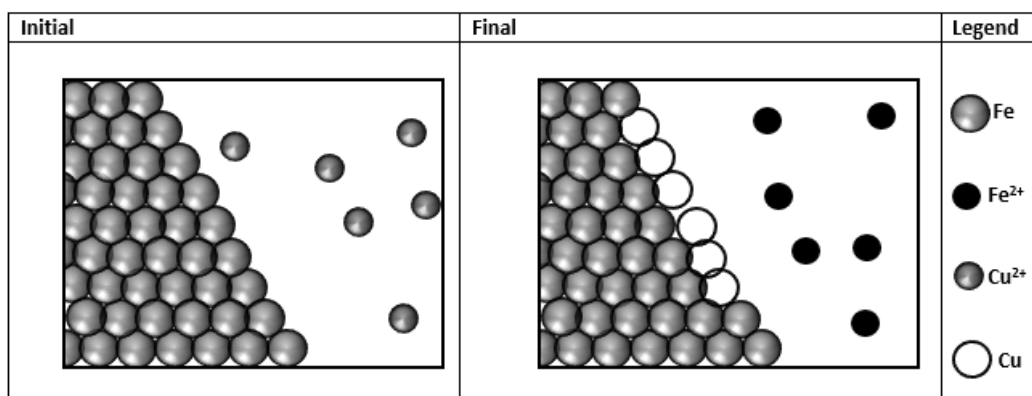


Figure 2. Representation of particle interaction, presented by the researcher - First interaction.

After the first step, it was repeated in the same sequence, but now with the chemical interaction between the steel wool and an aqueous solution of sulfuric acid. An example is shown in figure 3.

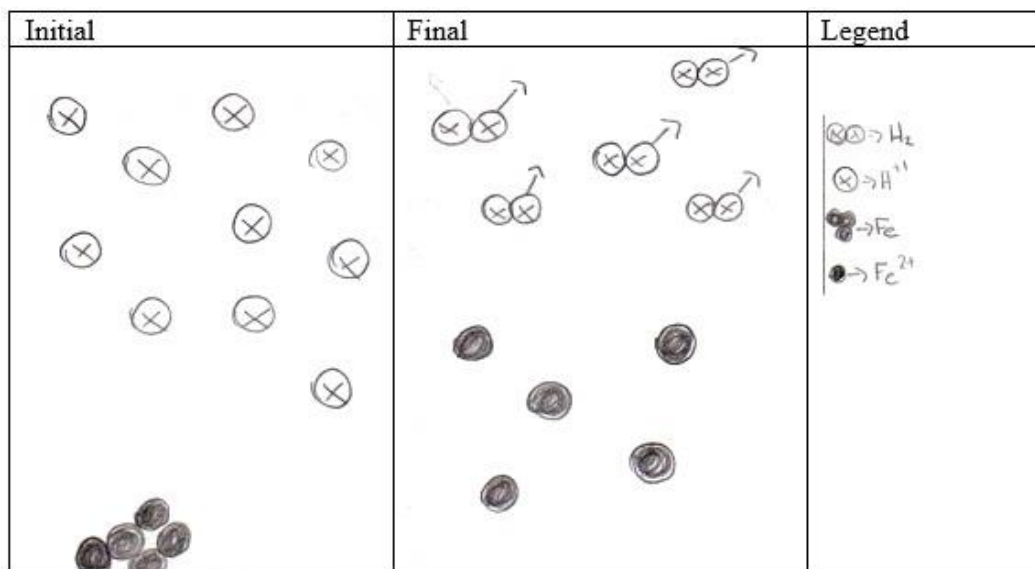


Figure 3. Representation of particle interaction, made by a pair of students - Second interaction.

Finally, there was collective discussion with students in the classroom, mediated by the teacher of the class.

RESULTS

Based on the registrations made by the students it was possible to identify at least three opportunities and two difficulties cited by them, see table 2. Also in the table 2, an example of speech of the groups about the ease or difficulty cited is indicated by the students.

Table 2. Opportunities and difficulties (limitations) provided by metavisual strategy

Opportunities	% (students)	Examples of speech of students
I. Recognition of differences in particle size	28.6	1. "Our design was very similar to these and we did not have great difficulty to compare."
II. Observe difference/make self-regulation/ratify	85.7	2. "When we compared it became much easier to understand what was wrong."
III. Comprehension how interactions happen.	21.4	3. "When we see the drawings, we understand how the reaction occurred, and it ended up helping us, so we had no trouble understanding."
Difficulties (limitations)	% (students)	Examples of speech of students
IV. Comprehension the transfer of electrons was not possible.	28.6	4. "We could not identify the difference in size between atoms was due to loss of electrons."
V. Partial comprehension of the representation of balls	57.1	5. "When looking at the image, we observed a significant difference. From this and the lack of a description of the systems, we had some difficulty in the analysis of proposed exercise."

DISCUSSION

Opportunities

The three elements cited by students as learning facilitators (I, II and III), indicate that working with images may have helped on rebuilding ideas, as to compare the drawings; the visual elements can help it. Of the total, 85.7% of students indicate the strategy as effective to some extent in this process, as it helps to identify possible errors and the discussion between them that enables to retake some misconceptions, common in teaching electrochemical or even can help to ratify some used reasoning. The difference in size, for example, that was reported by Rosenthal & Sanger (2012) was facilitated by the strategy, since 28.6% of the students were able to understand the difference by comparing images, as exemplified by the speech 1 (table 2). This was due to the comparison exercise, which allowed to redirect reasoning, as can be observed in the speech 2. Some students did not understand the interaction, as can be exemplified by the speech 3 (table 2), where 21.4% indicated the strategy as a facilitator in this regard. This is in accordance with what Rapp & Kurby (2008) score on the visualizations as an aid in the reconstruction of mental models. Thus, the role of metacognitive strategy can be a great help in understanding the phenomenon, allowing the student to self-regulate, for example, correcting any errors (speech 2) and also allowing him to ratify (speech 1 – table 2) what he had thought.

Limitations

Regarding these limitations (IV and V), it can be seen that some details cannot be perceived by the students, as quoted by them (28.6%) that, only with the mediation of the teacher, it was revealed that the difference in size due to electron transfer (speech 4 – table 2). Often, they can partially realize the error, but cannot rebuild (speech 5), perhaps for lack of theoretical baggage, difficulty in understanding the representations and previous ideas as pointed by Locatelli & Arroio (2014). The teacher's role is crucial (Locatelli & Arroio, 2014) since the students express in the drawings, which perhaps they could not verbalize, thereby the teacher mediating this process can lead them to the learning of concepts. This can be evidenced in speech 5, in which this difficulty was brought by 57.1% of students.

CONCLUSIONS

The strategy seems to have contributed to the learning, in the perception of surveyed students, as 85.7% of them said that, to some extent it was possible to self-regulation or ratification of their ideas. This is especially important in electrochemistry teaching, in which the concepts are complex. It is important to point out that the metavisual strategy provided both opportunities, as limitations to the learning of students who participated in this research. It is therefore critical that the teacher be aware of this to help as the conductor in the process, since 57.1% of students needed the help of the mediator to continue and reach the desired learning. It is recommended more studies on the subject, for example, understanding the factors that can bring limitations to the use of the strategy and how to get around them.

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ANALYZING TEACHERS' DISCURSIVE COLLABORATION IN A CO-TAUGHT SCIENCE-AND-ENGLISH CLIL CLASSROOM

Laura Valdés-Sánchez and Mariona Espinet
Universitat Autònoma de Barcelona, Catalonia, Spain

Abstract:

Two of the most important educational competences that promote the European Commission are the command of at least three languages and the understanding of Science. In response to the first demand, new foreign language teaching approaches have been promoted, such as *Content and Language Integrated Learning (CLIL)*. In Catalonia, a bilingual region of Spain, English is taught as a foreign and a third language, and CLIL projects often aim to integrate the teaching of Science and English. Science-and-English CLIL projects in Primary school represent a big challenge for primary teachers. They need to be capable to teach both disciplines in an integrated way and to preserve the quality in the teaching of both of them. Thus, the need to promote the dialogue among disciplines and the collaboration between experts in both fields arises. This research explores the potential of *co-teaching* as a strategy to help building a Science-and-English CLIL project in a public Primary school in Catalonia, Spain. We are interested in the interaction that occurs among co-teachers from different disciplines while they try to integrate the teaching of English as a Foreign Language and Science, and how this approach enriches the CLIL classroom and the professional development of these teachers. We take a methodological approach based on the discourse studies tradition from a sociocultural perspective. We undertake two types of analyses of their discursive collaboration: (a) a cross-sectional analysis of three pairs of co-teachers performing the same activity; and (b) a longitudinal study of one pair of co-teachers monitored along three years. We present in this paper the analytical tool, some preliminary findings, our future actions and the key factors we consider to describe a collaboration model in this co-taught Science-and-English CLIL project.

Keywords: Co-teaching, CLIL, Science Education, Discourse Studies, Teacher collaboration

INTRODUCTION

Our society and schools are multilingual and multicultural contexts embedded in a globalized world. The European educational institutions promote new teaching approaches related to bilingual education in order to encourage every citizen to acquire the command of at least three languages through compulsory education (Eurydice 2006, UNESCO 2003). Besides, the understanding of science is considered a necessary skill that needs to be also promoted, so that everybody can participate actively and critically in the functioning of our society (Eurydice 2011, COSCE 2011).

In this context of a multicultural and globalized world, CLIL (Content and Language Integrated Learning) projects have been promoted by the European commission as a way to improve the learning of a foreign language (Eurydice, 2006). The acronym CLIL is used as “a generic term to describe all types of provision in which a second language (a foreign, regional or minority language and/or another official state language) is used to teach certain subjects in the curriculum other than languages lessons themselves” (Eurydice, 2006, p. 8). In Catalonia, a bilingual autonomous community of Spain, English is taught as a foreign and a third

language. CLIL projects in this region often aim to integrate the teaching and learning of Science and English.

The Science teaching in English has been widely studied by the international educational research community (Escobar-Urmeneta, Evnitskaya, Moore, & Patiño 2011; Gajo, 2007; Valdés-Sánchez & Espinet, 2013.), which has documented both the benefits produced in the teaching of language and the benefits for Science education. In the case of Science teaching, the approach involves more focus on language through increased dialogue and negotiation (Moate, 2011), and therefore enhances the development of scientific competences since learning Science means learning to use the language of School Science. (Sanmartí, 2002; Edwards & Mercer, 1988; Mercer, 1997; Mortimer & Scott, 2003; Lemke, 1990).

Nevertheless, from the field of Science Education it should be noted that to initiate this kind of project teachers need to go far beyond simply explaining the subject in English. It involves collaboration between teachers in different specialized disciplines and reflection on how best a real integration between the learning objectives of the two subjects can be carried out (Dalton-Puffer, 2007; Valdés-Sánchez & Espinet, 2012). It also brings out the need for new professionals capable of integrating the teaching of Science and English without compromising the educational quality of both disciplines (Horrillo Godino, 2011; Sandberg, 2011).

Co-teaching is drawn as a strategy with great potential to help building discipline integration projects. Understood as a process in which two or more teachers plan, instruct and evaluate together (Davis Willey & Crespo, 1998), it involves collaborative work based on dialogue between disciplines that occurs inside and outside the classroom enriching learning environments with the baggage of two experts. Davis Willey and Crespo have collected some of the benefits of this practice documented by several researchers (Davis Willey & Crespo, 1998). Roth and Tobin (2007) advocate this model as a tool for professional development of teachers. They argue that teachers who work together in the classroom expand their identities through a cooperation based on established goals and interests.

This paper presents a research that explores the potential of *co-teaching* as a strategy to build a Science-and-English CLIL project conducted in a public Primary school in Catalonia. Through the analysis of the discourse of some pairs of co-teachers, it aims at illuminating some aspects of the interaction produced in this CLIL classroom. Its purpose is to reflect on (a) how the integration of Science teaching and English teaching occurs in the classroom, (b) what discursive collaboration models can we identify, and (c) how the discursive collaboration models evolve. We present the methodology developed to analyze the interaction among the co-teachers and some preliminary findings. In addition, we discuss our future actions and the key factors we consider important to describe a collaboration model in this co-taught Science-and-English CLIL project.

METHODOLOGY

Research design

The exploratory qualitative study presented in this paper adopts the assumptions on language and science education shared by the discourse studies community. We are interested in contributing to the understanding of “how learning occurs through language, how access to knowledge derives from participating in the social and symbolic worlds, and how disciplinary knowledge is constructed through language” (Kelly, 2007). The methodological approach draws from those discourse studies in science education that hold a sociocultural perspective (Edwards & Mercer, 1988; Lemke, 1990; Mercer 1997; Mortimer & Scott, 2003).

We focus on the interaction that occurs, in a discourse level, among co-teachers from different disciplines while they try to integrate the Foreign Language teaching and the Science Education, and how this approach enriches the CLIL classroom and the professional development of these teachers.

The data collection strategies included video recordings of full classroom interactions. During 2012-2013 we recorded the classroom interactions of 4 Primary teachers (one English teacher and three Science teachers) that were grouped into 3 pairs of co-teachers. Each pair was formed by the English teacher and one of the Science teachers, and they all performed the same activity in 3rd grade, within the subject "Knowledge of the natural and social environment". The recorded material was a hands-on activity about the properties of materials that follows a technological purpose (making an adobe) in a historical context (the houses in the prehistory). In addition, we also video recorded one primary science activity per year of one of the co-teachers pairs since the beginning of their collaboration in 2010-2011.

We are doing two types of analyses: (a) a cross-sectional analysis of three pairs of co-teachers performing the same activity in 2012-2013; and (b) a longitudinal study of one pair of coteachers (from 2010 to 2013). Data analysis was conducted in two phases: the macroanalysis and the microanalysis.

The macroanalysis phase started with the selection of the fragments of the activity where the co-teachers were constructing a discourse together, that is to say, the minutes of the video where the co-teachers were talking together with the whole class. The second step was the transcription of the selected fragments. Finally, we segmented these transcriptions according to their semantic pattern (Lemke, 1990) into our units of analyses: the episodes. An episode is a transcribed interactional sequence in which the co-teachers collaborate to complete a specific task with the whole classroom.

Once the macroanalysis is finished and we have obtained our units of analysis we have started what we call the microanalysis phase of our data analysis. Through an iterative process of analysis we have develop an inductive-deductive analytical tool. This tool has been validated with the collaboration of other researchers from the field of Science Education and Language Education. It helps us to do a qualitative analysis of each episode and to generate a coding system that will allows us to do a quantitative analysis. The study is in the phase of episode analysis. At the last stage of the microanalysis we will represent our results and we will: (a) compare the collaboration models of the three pairs of co-teachers in our cross-sectional study; and (b) analyze the evolution of the collaboration models of one of the pairs through the three years of their collaboration.

Analytical tool

We have developed an inductive - deductive analytical tool that has guided the process of coding. This tool is grounded on the analysis done in a preliminary research work (Valdés-Sánchez & Espinet, 2012), but it has been expanded with new theoretical as well as empirical contributions during data analysis. The analytical tool developed characterizes the episodes into three dimensions: (1) semantic pattern, (2) participation pattern and (3) linguistic pattern. It also characterizes how alternations and integrations among different categories occur within each pattern (Figure 1).

Figure 1. Analytical tool for qualitative analysis of the episodes

EPISODE NAME:		Code:		
FUNCTION:		Teachers' position:		
TURNS:		N° turns:		
QUALITATIVE DESCRIPTION:				
		Content	Participation pattern	Linguistic pattern
Semantic Pattern	Knowledge of the natural and social environment			
	Foreign Language			
	Management			
Alternations				
Integrations				

In the analysis of the semantic pattern, the teacher’s interventions are characterized in terms of its objectives in three classification systems: (a) purposes related to the “Knowledge of the natural and social environment” teaching, (b) purposes related to the English teaching and (c) purposes related to the management of the group. Each of the systems comprises several areas, and each area comprises different capabilities that can be materialized in discursive actions. The participation pattern points out and characterizes moments of individual or share leadership and the role of every teacher in the participation. Finally, in the analysis of the linguistic pattern we look for the moments when the co-teachers change the agreed linguistic pattern and we analyze the types of linguistic alternation and the causes that produce them. As an example, Table 1 is a reduced version of the categories used in the analysis of the semantic pattern.

Table 1. Reduced version of the semantic pattern categories table

Systems of categorization	Areas	Capabilities	Discursive actions
(a) Purposes related to the Knowledge of the natural and social environment teaching	Science and technology area	Scientific and technological knowledge	e.g. Defining
		Scientific practices	e.g. Asking questions
		Epistemological science and technology knowledge	e.g. Reflecting on utility of knowledge
	Socio-historic area	Socio-Historical knowledge	e.g. Situating on the historical time
	Attitudinal area	Attitudes	e.g. Taking care of the individual health
(b) Purposes related to the English teaching	Linguistic area	Lexical competence	e.g. Translating words
		Grammatical competence	e.g. Translating sentences
		Semantic competence	e.g. Using visual support such as flashcards
		Phonological competence	e.g. Exposing by oral repetition
		Orthographic competence	e.g. Spelling
		Orthoepic competence	e.g. Establishing the relationship among letter and sound
	Pragmatic area	Discursive practices	e.g. Describing

(c) Purposes related to the management of the group	Attitudinal area	Attitudes	e.g. Striving to understanding other
	Actors	Set up groups	e.g. Managing the arrival of new actors
		Set up rules	e.g. Specifying the code in use
	Materials	Material management	e.g. Managing materials
	Time	Time management	e.g. Ending an activity
	Space	Space management	e.g. Managing displacements
	Emotions	Emotional management	e.g. Motivating
Content	Content management	e.g. Locating the activity in the context of a wider action	

DISCUSSION AND CONCLUSIONS

The study presented in this paper is at present at the microanalysis phase and no results can be described yet. However, we discuss some findings of the preliminary study, some conclusions reached during the construction of the tools of analysis and a proposal for future work.

The preliminary study that focused only in the co-teachers' questioning, showed that co-teaching brings a reciprocal learning among teachers promoting: (a) change in the structure of the activity, (b) shared responsibility in the classroom, and (c) transfer among teachers on the ability to formulate scientific questions (Valdés-Sánchez & Espinet, 2012, 2013a, 2013b). The current study is expected to illuminate some features of the collaboration models of three pairs of Science-and-English CLIL co-teachers. We have found a useful way to describe these models through their decomposition into the semantic, the participation and the linguistic patterns. Moreover, we advocate for the alternations and integrations within each pattern as a good starting point to describe the collaboration models.

During the microanalysis phase of the current study we have started to establish relations between the semantic pattern, the participation of the co-teachers and the language in use. It will be interesting to analyze how this relationship evolves and how it differs between the three different pairs of co-teachers. About the semantic pattern, we have started to find moments of real integration among the teaching of Science and the English. We are interested in which linguistic practices can be related to the scientific practices in order to promote Inquiry Based Science Education and to avoid the reduction of the Language teaching to the lexical competence. In addition, during the analysis of the participation pattern, we have identified different strategies used by the co-teachers to share the leadership and co-construct a collaborative discourse. An interesting issue is how the teachers are managing their expertise and the different roles they can assume in this interdisciplinary context. Finally, we are interested in how the co-teachers use the linguistic alternations and microalternations to promote students' learning of Science and English. In conclusion, we would like to describe how co-teaching is helping to build this CLIL project and how it enriches the project and the professional development of the teachers involved.

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EXPLORING TEACHERS' SCIENCE INQUIRY PRACTICES AND STUDENTS' INQUIRY SKILLS

Dennis L. Danipog
University of Melbourne

Abstract: Inquiry has been an increasingly prominent theme of various science education reform movements worldwide. It is considered as a foundation of scientific literacy. However, many teachers do not typically use inquiry in their classrooms. This situation is one of the many challenges facing the basic science education in the Philippines. To counter this, the Philippine Department of Education initiated a curriculum reform that resulted in the implementation of the new science curriculum. This curriculum emphasizes the development of inquiry skills in addition to the acquisition of science content. This research proposal is designed to explore the nature of classroom instruction of teachers related to science inquiry as they implement the new curriculum. Research data will be gathered in four public secondary schools in Manila by employing two general procedures. Firstly is the assessment of science inquiry instruction using an observation tool. This will be done by conducting 5 one-hour class observations per teacher. Ten science teachers will be involved in this study. Teachers will be asked also to provide lesson plans to analyse their instruction related to science inquiry in conjunction with the observation notes. Secondly is the assessment of student inquiry skills using a science test. Pretest and posttest will be given to the students. This research will provide an evidence-based documentation of teaching practices that can foster science inquiry in classrooms. It can also inform education department on increasing teachers' capacity to use science inquiry practices associated with greater achievement of students in terms of inquiry skills.

Keywords: science inquiry, teachers, assessment

SCIENCE INQUIRY IN CLASSROOMS: PERSPECTIVES AND CHALLENGES

Inquiry has been a major theme of science curriculum improvement efforts worldwide since the time of John Dewey to the present (Wilson, Taylor, Kowalski, & Carlson, 2010). It has been considered to have a potential in promoting scientific literacy in classrooms (Flick & Lederman, 2004). There are three common perspectives on science inquiry. First, it is viewed as a process by which scientific knowledge is developed (Lederman, 2004). Second, it is viewed as classroom pedagogical approaches (DeBoer, 2004). Lastly, it is viewed as student learning outcomes (Flick & Lederman, 2004).

According to research, neither teachers nor students typically hold informed views of science inquiry (Schwartz et al., 2002; Lederman & Lederman, 2004; Lederman et al., 2014). As a result, most teachers have difficulty creating classroom environments that foster students' science inquiry skills (Lederman, 1992; McComas, 1998; Minstrell & van Zee, 2000; Lederman & Lederman, 2004). They tend to teach science as a collection of facts, principles, and concepts without explicitly instructing the processes by which scientific knowledge is generated and accepted.

It is unfortunate that the scenario described above can be seen in many science classrooms in the Philippines. However, recent efforts have been directed to improve science teaching and learning at the basic education in the Philippines. In 2012, the Department of Education

initiated a curriculum reform which resulted in the implementation of the Enhanced Basic Education (K to 12) Program. In this program, the new science curriculum emphasizes the development of inquiry skills in addition to the acquisition of science content (Department of Education [DepEd], 2013). Because of this reform, DepEd conducted a nationwide training of teachers focusing on the implementation of the new science curriculum. This research proposal aims to explore the nature of instruction of teachers particularly their enactment of inquiry practices as they implement the new science curriculum in Philippine classrooms. Specifically, it will focus on the following questions:

1. What teaching practices implemented by teachers exhibit elements of science inquiry?
2. What is the extent of implementation by teachers of these practices in classrooms?
3. What is the relationship between teachers' implementation of science inquiry practices and students' achievement of inquiry skills?

THEORETICAL FRAMEWORK

Inquiry as a model for pedagogy in science classrooms

Today, most instructional models used in science teaching seem to provide a useful framework for inquiry teaching and learning in the classroom (Marshall, Horton & Smart 2009). Because of the range of benefits that science inquiry has to offer, it is no surprise that educational leaders have endorsed it as a vital part of education over the years. Some of the major benefits of using science inquiry as a model of pedagogy in the classroom were outlined by DeBoer (2004) in his article entitled *Historical Perspectives on Inquiry Teaching in Schools*. These benefits are as follows:

1. Preparing students to become future scientists.
2. Developing citizens who may not become scientists themselves but who will be autonomous, independent thinkers.
3. Strengthening students' understanding of the methods, content, and principles of science.
4. Providing students more control over their own learning.

There is no single method of teaching science inquiry in classrooms (National Research Council [NRC], 2000). It involves a broad array of approaches that usually has a problem to be solved or a question to be answered. To know more about the essential components of this pedagogical approach, a summary of each contemporary science inquiry instructional model used in classrooms is presented below. In this study, five models were chosen to review as these models are designed for K-12 classroom settings, have reference to a constructivist or socio-constructivist focus and are more directly focused on students learning science in an inquiry environment.

The 5E Instructional Model

This model consists of five phases—the 5 Es—engage, explore, explain, elaborate, and evaluate (BSCS and IBM, 1989; Bybee, 2004).

Table 1. Phases of 5E instructional model

Phase	Summary
Engagement	Students should become mentally engaged in the concept, process, or skill to be explored
Exploration	Students actively explore their environment or manipulate materials
Explanation	Students pay attention on a particular aspect of their engagement and exploration experiences and provide opportunities for them to verbalize their conceptual understanding, or demonstrate their skills or behavior
Elaboration	Students are given opportunity to extend their conceptual understanding and allows them to practice skills or behavior to develop deeper and broader understanding, more information, and adequate skills
Evaluation	Students are encouraged to assess their understanding and abilities

The Guided-Inquiry Model

This model consists of five phases— engage, prepare to investigate, investigate, prepare to report, and reporting (Magnusson & Palincsar, 1995; Magnusson, Palincsar, & Templin, 2004).

Table 2. Phases of guided-inquiry model

Phase	Summary
Engage	Students are engaged in questioning
Prepare to investigate	Students are involved in preparing questions, materials, methods, design, and test of explanation
Investigate	Students derived knowledge claims about the physical world
Prepare to report	Students are asked to determine claims and evidence
Reporting	Students are asked to share publicly the results of their investigative activity

Essential Features of Science Inquiry

The NRC (2000) through its *Inquiry and the National Science Education Standards* outlines the following fundamentals of inquiry in science classrooms. These features have been extensively used in science education research as a framework for discussing inquiry-based instruction in classrooms.

Table 3. Features of inquiry

Essential Features	Summary
Engages in scientific-oriented questions	Students are involved in a scientifically-oriented question
Collects evidence	Students give priority to evidence in responding to the question
Formulates explanations from evidence	Students use evidence to develop an explanation
Connects explanations with knowledge	Students connect explanation to scientific knowledge
Communicates and justifies explanations	Students communicate and justify the explanation

The ESTABLISH Model of Inquiry-Based Education (IBE)

In one of the European Union (EU) funded research projects called the *European Science and Technology in Action Building Links with Industry, Schools and Home (ESTABLISH)* project, fundamental abilities of IBE were outlined based on nine elements of IBE proposed by Linn, Davis, and Bell (2004). Most of these elements are explicitly stated or implied in the national curricula of the 11 European countries which participated in the ESTABLISH project.

Table 4. Fundamental abilities of IBE (McLoughlin, 2011)

Aspect of IBE	Fundamental abilities according to the ESTABLISH project
Diagnosing problems	Students identify the core of the problems/questions Students understand and use their prior knowledge to be able to form working hypothesis
Critiquing experiments	Students formulate arguments Students state outcomes in a comparative way Students suggest further developments
Distinguishing alternatives	Students identify key elements of the problem Students identify ranking level for key elements Students express alternatives in suitable form
Planning investigations	Students establish the hypothesis in a realistic way towards a goal Students consider the hypothesis and methods of answering the hypothesis Students set a time frame, steps involved, resources required and training in use of any equipment Students monitor and review the approach
Researching conjectures (hypothesis testing)	Students test hypothesis which follow from their observations, facts previously gathered, or preliminary theories
Searching for information	Students define what they need to search using the right resources and how to do this and where Students identify possible sources of information relating to possible intervening variables
Constructing models	Students try to find something that: enables description, understanding, explaining, and prediction can be checked, proved, disproved, adapted, improved, or abandoned
Debating with peers	Students discuss and regard different interpretations of experimental results Students work cooperatively and collaboratively
Forming coherent arguments	Students build on evidence/information so as to be able to present this as a logical, evidence-based communicative format, e.g. model, solution/conclusion to the process that explains and may include evidence for and against

Scientific Practices for K-12 Classrooms

In the new framework for K-12 science education in the United States, NRC (2012) outlined eight scientific practices that are essential elements for K-12 science curriculum. These practices are derived from those that scientists and engineers actually engage in as part of their work.

Table 5. Scientific practices

-
1. Asking questions
 2. Developing and using models
 3. Planning and carrying out investigations
 4. Analyzing and interpreting data
 5. Using mathematics and computational thinking
 6. Constructing explanations
 7. Engaging in argument from evidence
 8. Obtaining, evaluating, and communicating information
-

Although it is acknowledged that there is no single method of teaching science inquiry in the classroom, most of the key features of the models reviewed in this paper confirmed the commonalities in the following essential elements of science inquiry in the classroom:

1. Engaging in questioning
2. Designing investigations
3. Collecting and organizing data
4. Analyzing and interpreting data
5. Formulating explanations and conclusion
6. Communicating information

The aforementioned instructional models of science inquiry are developed based on solid research or they may expand on previous models, but it is a must for teachers to become evaluative in employing the right instructional model to determine if a model-based approach is really an effective means to implementing science inquiry in classrooms.

METHODS

A series of classroom observations will be performed to identify: (1) specific teaching practices that teachers employ that show elements of science inquiry, including the multiple ways in which teachers support the development of students' inquiry skills, and (2) the extent to which teachers implement these practices in classrooms. A classroom observation instrument was developed which includes 29 statements about inquiry teaching practices, which are grouped into 6 elements of science inquiry—questioning, designing experiment, collecting data, analysing data, developing explanation, and communicating information. The actual observation will be conducted in each teacher's class for 5 one-hour lessons. It will be undertaken in four public secondary schools in Manila during the first quarter of school year 2015-2016 with ten Grade 7 science teachers who participated in the new science curriculum training program.

In addition to actual classroom observations, teachers will be asked to provide a written description of their lesson plans and other relevant teaching materials used in the lesson to analyse their instruction related to science inquiry in conjunction with the classroom observation notes.

After characterising teacher's science inquiry practices in the classroom, the relationship of implementation of these practices to students' achievement of inquiry skills as outlined in the new science curriculum will be examined. To measure Grade 7 students' achievement, they will be given pretest and posttest of science inquiry skills. The Assessment Research Centre of the University of Melbourne in collaboration with the Assessment, Curriculum and Technology Research Centre of the University of the Philippines has designed a multiple-choice test of science inquiry skills. The test has been designed for students in lower secondary school. It covers inquiry skills across a range of difficulty, from simple measurement and classification tasks through to control of several variables and interpretation of multivariate data. As the purpose of the test is to assess students' science inquiry skills, the test has been designed to be as content-free as possible. This enables the science inquiry skills of the students to be assessed without interference caused by differences in knowledge of science content due to different curricula. Care has also been taken to minimise the reading load of the test as much as possible.

IMPLICATIONS

This project will:

1. Provide an evidence-based documentation of science inquiry teaching practices associated with students' improvement of inquiry skills.
2. Inform Philippine Department of Education on teachers' implementation of science inquiry practices as they teach the new K to 12 science curriculum.

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OVERCOMING THE BELIEF IN RELATIONSHIP BETWEEN EARTH'S ROTATION AND MOON PHASES

Shuichi Yamashita, Hideki ITOU and Michiyo SIBATA

Chiba University, Japan

Abstract: The purpose of this study was to investigate junior high school students', university students' and elementary teachers' belief in the relationship between the earth's rotation and the different moon phases, and also to determine how the improved model and reading materials facilitate their understanding of the real cause of moon phases.

First, 28 elementary education students received instruction for 40 minutes about the causes of moon phases, using the original model for elementary-level science. Out of the 28 students, 17 believed that there is a relationship between the rotation of the earth and the phase of the moon, even after instruction was given.

Second, 33 science course students, 57 elementary school teachers, and 256 junior high school students received 40 minutes of instruction by using the improved model with the reading material, and their understanding of the cause of moon phases was evaluated by a pre-test and post-test.

The research yielded the following three results:

1. A total of 3 (9.1%) science course students and 14 (24.6%) elementary teachers believed the earth's rotation affects moon phases.

2. A total of 21 (63.6%) science course students and 49 (86.0%) elementary school teachers could not explain the cause of moon phases at the pre-test. However, all of the science course students and 57 (96.5%) elementary teachers were able to explain the same, more completely than the textbook, at the post-test. None of them mentioned the effects of the earth's rotation on moon phases.

3. At the pre-test, 33 (12.9%) junior high school students believed that the earth's rotation affects moon phases, and 86 (33.6%) junior high school students could not explain the cause of moon phases. However, at the post-test, 235 (91.8%) junior high school students were able to explain the cause more completely than the textbook.

Keywords: moon phases, rotation of the earth, improved model

INTRODUCTION

The Japanese course of study for elementary and secondary school was announced in 1999. Though comprehensive, it did not include a unit about moon phases. However, the topic was included in the 2008 update to the course of study. Therefore, Japanese university students and young teachers who were taught under the 1999 course of study did not learn about moon phases when they were in elementary and secondary school. It is because of this situation that the need to develop new teaching materials arises. New teaching materials will help them in their learning and teaching.

There are some differences in the teachings about moon phases between sixth and ninth grades in Japan. Sixth grade students are taught that the moon phases change by observing them from the earth, while ninth graders are taught that it is by the relative positions of the earth, sun, and moon. As the result of these differences, some students might cite the earth's rotation on its axis as a contribution to the cause of moon phases. Some researchers (e.g., Sharp, 1996; Stahly et al., 1999) have discussed the effects of the earth's rotation on the different moon phases. On the other hand, only a few researchers focused on that in Japan (e.g., Yanagimoto & Ohtaka, 2008; Yunoki, 2014). Trundle, Atwood, and Christopher (2002) reported that 6 of 57 (10.5%) preservice elementary teachers indicated, during an interview in the United States, that the earth's rotation on its axis contributes to the phases of the moon.

Japanese educators must examine this misconception of the earth's effect on the cause of moon phases and try to overcome it with the new teaching materials. To meet these needs, the following research questions were addressed through a qualitative and quantitative research design.

- 1) Before instruction, how do university students and elementary teachers describe the effects of the earth's rotation on the occurrence of moon phases?
- 2) Why do university students think that the earth's rotation affects moon phases?
- 3) How do the new teaching materials facilitate junior high school students', university students' and elementary teachers' understanding of the causes of moon phases?

METHOD

Design and Participants

1) A total of 55 elementary education course national university students were divided into two groups (A: 27, B: 28) randomly in 2014. Each member of Groups A and B received 40 minutes of individual instruction about the causes of moon phases. Group A used the improved model with reading material, while Group B used the original model for elementary-level science. These students were asked to answer the questions on the post-test. A group of 18 students (A: 1, B: 17) believed that the earth's rotation causes moon phases even after viewing the instructional material.

2) A total of 33 science course private university students and 57 elementary teachers received 40 minutes of individual instruction in 2014 on the cause of moon phases, using the improved model with the reading material. They were asked to answer the pre-test and post-test questions.

3) A total of 256 junior high school students who had just learned the moon phases were tested in 2015 by the same procedure described in 2), above.

Data Analysis

1) The answers of the test were assigned values from Level 0 to Level 2 as follows.

Level 0: Wrong answer or no response.

Level 1 (Textbook-level understanding): The answer mentioned that the relative positions of the earth, sun and moon determine the phase, or that the moon orbits the earth.

Level 2 (Higher-level understanding): The answer mentioned that the moon orbits the earth, and that during a typical cycle of phases, half of the moon always is illuminated by the sun.

2) Audiotapes of the interviews were transcribed and the transcripts were divided into four categories (a: student confused by diurnal motion, b: student thought the moon was observed on the earth, c: student could not visualize the moon orbiting the earth, d: student was affected by the original model that showed the viewing from the earth).

Instructional Context

We developed five pages of reading material to teach about the moon phases. The reading material consists of four components that explain the moon phases; they are provided as follows (Trundle, Atwood, & Christopher, 2002).

1) The sun is located quite far from the earth and the moon.

2) Half of the moon is always illuminated by the sun.

3) The moon orbits the earth.

4) The relative positions of the earth, sun and moon determine the portion of the lighted half seen from the earth.

We also improved the original model of the moon phases for secondary-level science. The original model has good points, in that it is: 1) three-dimensional, which makes it easier to understand the location of planets, 2) easy to understand where the moon and the sun are in each moon phase and why the moon appears to be the shape we see from earth, and 3) inexpensive to purchase enough models for all of the students in a class. However, we have to teach the relationships between the azimuth, diurnal motion and earth's rotation at secondary-level science. We improved the original model to put a small circle sheet in the middle to explain the cause of moon phases (Figure 1).



Figure 1. The original model and the improved model with the reading material.

In Group A, junior high school students, science course students and elementary teachers received 40 minutes of instruction using the improved model with the reading material.

RESULTS

Comparison between Groups A and B

1) Results of the post-test

Group A and B students' answers on the post-test were assigned values from Level 0 to Level 2 (Table 1).

Table 1. Results of the post-test.

Level	Group A (n=27)	Group B (n=28)
2	15 (55.6%)	4 (14.3%)
1	10 (37.0%)	7 (25.0%)
0	2 (7.4%)	17 (60.7%)

After instruction, 25 (92.6%) Group A and 11 (39.3%) Group B students could explain the cause of moon phases at more than the textbook level. Furthermore, 15 (55.6%) Group A and 4 (14.3%) Group B students could explain that the moon orbits the earth, and that during a typical cycle of phases, half of the moon always is illuminated by the sun.

Even after instruction, 18 students (A: 1 (3.7%), B: 17 (60.7%)) mentioned the effects of the earth's

rotation on the cause of moon phases.

2) Results of the interview

During interviews, 18 students (A: 1, B: 17) were asked why the earth's rotation affects moon phase. In Group A, only one student answered that the moon was observed on the earth, and it was difficult to visualize the moon orbiting the earth. On the other hand, in Group B, 9 (52.9%) students were confused by diurnal motion, 7 (41.2%) students were effected by observing from the earth, 1 (5.9%) student could not visualize the moon orbiting the earth, and 7 (41.2%) students were effected by the original model that showed the view from the earth.

Comparison between science course students and elementary teachers

The students' and teachers' answers were assigned values from Level 0 to Level 2 (Table 2).

Table 2. Results of the science course students' and elementary teachers' pre-test and post-test.

Level	science students ($n=33$)		elementary teachers ($n=57$)	
	pre-test	post-test	pre-test	post-test
2	0 (0.0%)	20 (60.6%)	2 (3.5%)	33 (57.9%)
1	12 (36.4%)	13 (39.4%)	6 (10.5%)	22 (38.6%)
0	21 (63.6%)	0 (0.0%)	49 (86.0%)	2 (3.5%)

At the pre-test, 12 (36.4%) science course students and 8 (24.6%) elementary teachers could explain the cause of moon phases at more than the textbook level. Another 3 (9.1%) science course students and 14 (24.6%) elementary teachers mentioned the effects of the earth's rotation as a cause of moon phases.

In the post-test, all science course students and 55 (96.5%) elementary teachers could explain the cause of moon phases at more than the textbook level. Furthermore, 20 (60.6%) science course students and 33 (57.9%) elementary teachers could explain that the moon orbits the earth, and that during a typical cycle of phases, half of the moon always is illuminated by the sun. None of the science course students or elementary teachers mentioned the earth's rotation as affecting moon phases at the post-test.

Results of the junior high school students

The junior high school students' answers were assigned values from Level 0 to Level 2 (Table 3).

Table 3. Results of the junior high school students' pre-test and post-test.

Level	junior high school students ($n=256$)	
	pre-test	post-test
2	43 (16.8%)	134 (52.3%)
1	127 (49.6%)	101 (39.5%)
0	86 (33.6%)	21 (8.2%)

At the pre-test, 43 (16.8%) students believed that the earth's rotation affects moon phases, while 86 (33.6%) students could not explain the cause of moon phases.

At the post-test, only 9 (3.5%) students mentioned the effects of the earth's rotation as a cause of

moon phases, while 235 (91.8%) students were able to explain the correct cause more completely than the textbook.

DISCUSSION AND CONCLUSIONS

Only a few recent Japanese research reports mention the earth's rotation as a cause of moon phases. We confirmed with 3 of 33 (9.1%) science course students and 14 of 57 (24.6%) elementary teachers that they were not comprehensively informed about the earth's rotation and its effect on the occurrence of moon phases when they took the pre-test (Research Question 1). With this, we conclude that there is a need to overcome the effects by developing a new way of teaching.

Even after receiving instruction using the original model, 17 of 28 (60.7%) Group B students mentioned the effects of the earth's rotation in the cause of moon phases. There are several reasons for their belief. For example, 52.9% of them confused rotation with diurnal motion, while 41.2% of them were effected by observing from the earth (Research Question 2). These things were triggered by using the original model for elementary-level science. At that level, teachers could teach the moon phase phenomenon only by observing from the earth. We needed to improve the original model and develop the reading material to understand the cause of moon phases.

The results of comparison between science course students and elementary teachers showed that 21 (63.6%) science course students and 49 (86.0%) elementary teachers could not explain the cause of moon phases at the pre-test. However, all science course students and 57 (96.5%) elementary teachers could explain the cause of moon phases at more than the textbook level after taking the post-test. None of them mentioned the earth's rotation as a cause of moon phases. Previous research (e.g., Stahly et al., 1999; Ogiwara & Kobayashi, 2010) took more than two weeks to achieve similar results. This research's instruction took only 40 minutes, so it is possible to say that the improved model with the reading material effectively facilitated university students' and elementary teachers' understanding of the cause of moon phases.

The results of the junior high school students showed that there was room for improvement in their understanding of the cause of moon phases even just after taking school lessons. At the pre-test, 33 (12.9%) junior high school students believed the earth's rotation causes the phases, and 86 (33.6%) junior high school students could not explain the cause at all. However, at the post-test, 235 (91.8%) junior high school students were able to explain the actual cause more completely than the textbook, and only 9 (3.5%) junior high school students mentioned the effects of the earth's rotation on moon phases (Research Question 3).

From these results, it is possible to say that the improved model with the reading material effectively facilitated the students' and teachers' understanding of the cause of moon phases.

For further research, we should develop a well-connected curriculum between elementary and secondary level science of the moon phases in the near future.

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INQUIRY-BASED SCIENCE EDUCATION: TOWARDS A PEDAGOGICAL FRAMEWORK FOR PRIMARY SCHOOL TEACHERS

Martina S. J. van Uum¹, Roald P. Verhoeff² & Marieke Peeters³

¹Science Education Hub Radboud University, the Netherlands

²Freudenthal Institute, Utrecht University, the Netherlands

³HAN University of Applied Sciences, the Netherlands

Inquiry-based Science Education (IBSE) promotes pupils' curiosity and understanding of the process of scientific inquiry. Open IBSE enables pupils to formulate their own research question and to design and conduct their own scientific investigation. Unfortunately, primary school teachers often lack competence in guiding the self-directed process of open IBSE. They are insecure about how to support their pupils during the different phases of inquiry. In addition, they lack knowledge about what the focus of their support should be, such as facilitating procedures or conceptual knowledge. To address these challenges we developed a pedagogical framework for teachers to support the inquiry process of their pupils. Based on a literature study our framework distinguished four domains of scientific knowledge that are important to address during open inquiry: the conceptual, social, procedural, and epistemic domain (what scientific knowledge is and how it is generated). Furthermore, we elaborated different phases of inquiry: e.g. exploration, research design, conducting investigations, and conclusion. Subsequently, we investigated for each phase of inquiry which domains of scientific knowledge teachers should address to support the inquiry process of their pupils. We did a multiple case study in which we observed and analysed seven IBSE projects of the Dutch Science Education Hub Radboud University (WKRU). The analysis of the seven IBSE projects refined our pedagogical framework. Our results provide insight into the importance of addressing specific domains of scientific knowledge in the subsequent phases of inquiry. The framework facilitates teachers to support their pupils during the process of inquiry.

Key Words: Inquiry-based science education, Teacher professionalisation, Pedagogical framework

Inquiry-based science education (IBSE) is considered an important approach in science education to contribute to an understanding of science and its processes (Minner, Levy & Century, 2010). In the Netherlands all primary schools have to address science and technology by the year 2020 (Techniekpact, 2013). To contribute to this objective the current study focuses on the professionalisation of primary school teachers regarding open IBSE to support the inquiry process of their pupils.

There are different levels of IBSE depending on the support of pupils that teachers provide. For example, in structured IBSE the teacher presents a research question and decides how pupils investigate this research question. Subsequently, the pupils analyse the results and draw conclusions. In contrast, open IBSE allows pupils to be more self-directed and to formulate their own research question regarding a topic of their interest related to the theme of the classroom project. Furthermore, they plan and conduct their own investigation to answer the question (Windschitl, 2003). Unfortunately, many teachers regard it as challenging to support their pupils in self-directed learning during the process of open inquiry (Zion, Cohen & Amir,

2007). They, for example, experience problems with facilitating pupils to design investigations and to draw conclusions. As a result, pupils' research designs are not always in line with their hypotheses and their conclusions sometimes consist of a list of results without an answer to their research question. Moreover, some teachers provide too much structure while others are too reserved in their guidance during the open inquiry process (Yoon, Joung & Kim, 2012). Addressing the barriers that hinder teachers in guiding open IBSE, this paper presents a pedagogical framework to support them in their classroom practice.

To develop the pedagogical framework we distinguished four domains of scientific knowledge that are important to address during IBSE: the conceptual, epistemic, social and procedural domain (Duschl, 2008; Furtak, Seidel, Iverson & Briggs, 2012). The conceptual domain consists of a body of knowledge regarding the understanding of natural phenomena, such as the concept of electricity (Boekaerts & Simons, 1995). The epistemic domain refers to the nature of scientific knowledge and how it is generated, e.g. scientific knowledge is tentative and future investigations can change our current understandings (Furtak et al., 2012; Lederman, 1992). The social domain implies collaboration and communication of scientific ideas, responsibilities and results. For example, a presentation to explain the research to an audience (Mercer, Dawes, Wegerif & Sams, 2004; Peeters, Meijer & Verhoeff, 2014). Finally, the procedural domain comprises inquiry procedures, such as the formulation of a research question (Boekaerts & Simons, 1995; Peeters et al., 2014). Together these four domains provide the basis for a coherent understanding of scientific inquiry to be achieved in IBSE.

In addition to the four domains of scientific knowledge we distinguished the following seven phases which together constitute an inquiry cycle: introduction, exploration, designing an investigation, conducting the investigation, conclusion, presentation/communication and deepening/broadening of the acquired knowledge and skills. These phases of Van Graft and Kemmers (2007) are used in most inquiry-based projects in the Netherlands. To clarify the guidance of the inquiry process by teachers, we formulated the following central question: How can primary school teachers support their pupils during open IBSE? Our hypothesis is that in each phase of inquiry specific domains of scientific knowledge are essential to be addressed by teachers to enable their pupils to progress through the inquiry process.

METHOD

To find out how the domains and phases described above, could be optimally combined in classroom practice we did a multiple case study in which we observed and analysed seven IBSE projects in practice of the Dutch Science Education Hub Radboud University (WKRU). By analysing video clips of these projects we intended to clarify for each phase of inquiry which domains of scientific knowledge were important to address by the teacher to enable pupils' inquiry process. WKRU has been chosen for our study, because it has numerous experiences with IBSE. WKRU assembles academic scientists and in-service and pre-service primary school teachers in project teams to translate current research of Radboud University into IBSE activities for primary school pupils aged 10 to 12. Subsequently, the primary school teachers conduct these projects in their own classrooms.

The selected seven projects consisted of five to nine inquiry-based lessons of about one hour each. We conducted a qualitative analysis of the video recordings of these lessons. First, we observed each video and labelled the different IBSE phases. Within each labelled phase we selected fragments containing teacher and pupil comments regarding one of the four domains of scientific knowledge. Subsequently, we analysed whether pedagogical interventions by the

teacher resulted in pupils' understanding of the domains of scientific knowledge which enabled them to progress through the subsequent phases of inquiry. For example, a teacher explained the importance of including a considerable amount of research subjects in the investigation. Subsequently, a group of pupils decided to increase this amount in their own investigation. Furthermore, we analysed additional consequences of teacher interventions in the subsequent inquiry phases, such as a presentation by pupils in which they described that they indeed included a significant amount of research subjects in their investigation. Finally, the results of the different WKRU projects were compared with each other to determine which teacher actions resulted in expressions of understanding by pupils and a successful progression through the inquiry process.

RESULTS

In this section we will discuss a qualitative description of the observed teacher interventions that were regarded as successful to support pupils' inquiry process. Table 1 provides an overview of the added value of addressing specific domains of scientific knowledge in the subsequent phases of inquiry.

Table 1. The added value of addressing specific domains of scientific knowledge in the subsequent phases of inquiry.

Phase	Domain	The added value of addressing specific domains of scientific knowledge in the subsequent IBSE phases enabled pupils to...
1 Introduction	Epistemic	...understand the link between their own project and research of real scientists
2 Exploration	Conceptual	...differentiate between their acquired knowledge and the knowledge they still want to acquire
3 Designing an investigation	Procedural	...perform the procedure of constructing a research question
	Epistemic	...consider the number of research subjects and measurements needed to conduct the investigation
	Social	...work together during the inquiry process
4 Conducting the investigation	Procedural	...make correct measurements and take organised notes
5 Conclusion	Procedural	...refer back to the research question when drawing a conclusion
	Epistemic	... differentiate between results, conclusion and discussion

6	Presentation/ communication	Social	...explain the research to an audience
7	Deepening/ broadening	Reflection and further elaboration	...reflect on acquired knowledge and to further deepen/broaden their knowledge

We will discuss the results in Table 1 by describing for each phase of inquiry the specific domains of scientific knowledge that were important to be addressed in the projects that we analysed. In addition, to clarify the results we provide examples regarding one of the seven projects: the project on DNA and heredity.

To introduce the IBSE projects it was important to stimulate pupils' curiosity regarding the project theme and to link the project to authentic scientific research. The teacher of the project on DNA and heredity introduced her project by arranging an activity in which pupils were divided into groups that shared similar physical characteristics. At the end of the activity it turned out that each child possessed a unique combination of physical characteristics. Furthermore, the teacher linked the project to authentic scientific research to promote epistemic understanding and explained that pupils were going to conduct similar investigations.

Retrieving pupils' prior knowledge and increasing their conceptual understanding regarding the theme of the classroom project was essential in the exploration phase of inquiry. To address conceptual understanding teachers linked new concepts with relevant everyday contexts and combined hands-on activities with minds-on reflections about these activities. This enabled pupils to differentiate between acquired knowledge and their remaining questions. In the project on DNA and heredity the teacher explained the process of cell division by referring to a copier that worked day and night. Furthermore, she mentioned pieces of Lego in different colours that could be connected to each other, to explain the coding of physical characteristics by means of DNA sequences. In addition, the teacher provided hands-on science activities for her pupils, such as making their own DNA sequence by using codes that represented their physical characteristics. Furthermore, she stimulated pupils to discuss and reflect on the hands-on activities and the knowledge they acquired. Subsequently, she made a question wall. One part of the wall referred to knowledge pupils possessed and another part contained questions about knowledge that pupils lacked and wanted to acquire by means of an inquiry. This enabled pupils to formulate research questions in the subsequent phase of inquiry.

During the design of the investigations it was important to focus on the generation of scientific knowledge, on social understanding of research collaboration and communication, and on how to formulate a research question. Teachers addressed the latter by scaffolding this procedure. Furthermore, pupils' collaboration and communication about their investigations was facilitated, for example, by dividing roles, such as chairman and minutes secretary. Finally, teachers explained design criteria of a proper investigation to address the generation of scientific knowledge. In the current phase of inquiry the teacher of the project on DNA and heredity stimulated her pupils to think about controlling variables to design a proper investigation. For example, by explaining that there is a difference between a newborn baby and a baby aged two, to pupils that wanted to include babies in their investigation. Subsequently, she stimulated these pupils to select babies of about the same age for their investigation. Furthermore, the teacher addressed the social understanding of her pupils by explaining the importance of asking for permission before involving research subjects in an investigation. Finally, she explained criteria

of formulating a research question, such as “the answer to the question is unknown to the pupils”. Attention for the three domains of scientific knowledge mentioned, enabled pupils to continue with the subsequent phase of inquiry.

In the phase of conducting the investigation teachers discussed procedures, such as making precise measurements, to enable pupils to conduct reliable investigations. In the project on DNA and heredity the procedural knowledge in this phase of inquiry concerned, for example, knowing how to adjust the lens of a microscope to get a clear view of cells to include in the investigation. Subsequently, in the conclusion phase it was important to discuss the difference between results, conclusion and discussion, and to provide explanations to support the drawing of a conclusion. Unfortunately, the teacher of the project on DNA and heredity did not provide an instruction or explanations in the current phase of inquiry. As a consequence, not all groups of pupils were able to draw a conclusion. Teachers of other projects discussed relevant everyday contexts to explain the difference between results, conclusion and discussion. Furthermore, they facilitated the drawing of conclusions by explaining how to connect data to the research question that pupils had formulated before the conduction of the investigation.

Subsequently, it was essential to address pupils’ communication about their investigations to an audience. To improve pupils’ social understanding teachers facilitated reflection by means of feedback on pupils’ presentations. The teacher of the project on DNA and heredity promoted reflection about the presentations just after pupils presented their research. She provided feedback to her pupils and enabled pupils to give each other feedback about how to present research in a clear and organised way. Finally, in the deepening/broadening phase of inquiry all domains of scientific knowledge can be reflected on and can be further deepened or broadened. The teacher of the project on DNA and heredity decided to visit a DNA lab with her pupils to further deepen their conceptual knowledge about DNA and their epistemic knowledge about what science is and how it is generated. Furthermore, pupils acquired procedural knowledge about how to isolate their own DNA.

DISCUSSION AND CONCLUSIONS

Based on a literature search and analyses of video clips of open IBSE projects we constructed a pedagogical framework which teachers can use during their pedagogical guidance of pupils in open IBSE. Our literature study resulted in four domains of scientific knowledge and seven IBSE phases. We used this preliminary framework of domains and phases to analyse video clips of open IBSE projects. Our qualitative analyses showed that it was important for teachers to address specific domains of scientific knowledge in each phase of inquiry to effectively support their pupils during the process of open inquiry.

To enable pupils to conduct investigations it was important to address all four domains of scientific knowledge during the preparation of the investigations and to shift in focus between these domains. When exploring the theme of the investigation, for example, it was important to address the conceptual domain of scientific knowledge in order for pupils to differentiate between their acquired knowledge and their remaining questions, and to formulate a research question in subsequent phase of inquiry. Subsequently, in the phase of designing the investigation teachers focused on procedural knowledge, such as formulating a research question; social knowledge about research communication and collaboration; and epistemic knowledge about how to plan a proper investigation. By addressing these domains of scientific knowledge in the preparation phases of inquiry pupils were enabled to conduct their investigation in the next phases of inquiry. During and after the conduction of the investigations it was important to address the domains of

scientific knowledge a second time. Teachers, first, addressed procedures, such as making correct measurements to promote reliable investigations. Second, they discussed the difference between data, conclusion and discussion and explained a procedure to support the drawing of a conclusion. Subsequently, the focus of teachers shifted to research communication in the presentation phase to facilitate pupils to present their research in a clear and organised way. And finally, in the phase of deepening/broadening the domains of scientific knowledge were reflected on and further deepened or broadened.

Different teacher strategies were used to improve pupils' understanding regarding the four domains of scientific knowledge. To improve conceptual understanding it was essential to link concepts with relevant everyday concepts (Van Graft, Boersma, Goedhart, Van Oers & De Vries, 2009) and to focus on minds-on reflections during and after hands-on science activities (Abrahams & Millar, 2008). As a consequence, pupils were enabled to differentiate between the knowledge they acquired and their remaining questions to be investigated. Procedures, such as formulating a research question, were clarified by means of questioning (School aan Zet, 2014) and scaffolding (Saye & Brush, 2000). This allowed pupils to design and conduct their investigations and to draw conclusions in order to answer their research question. Furthermore, pupils' collaboration was promoted by distinguishing roles, such as chairman and minutes secretary (Johnson & Johnson, 2009). In addition, reflection about research communication was facilitated by providing feedback on pupils' presentations (Van der Schaaf, Baartman, Prins, Oosterbaan & Schaap, 2013). By improving their social knowledge pupils were enabled to collaborate within their research groups and to explain their research to an audience. Finally, epistemic knowledge was addressed by referring to authentic scientific investigations, by questioning pupils about how to plan a proper investigation and by explaining the difference between data, conclusions and discussion when drawing a conclusion. By means of these explanations pupils linked their investigations with real scientific research and improved their understanding of what scientific knowledge is and how it is generated (Furtak, 2006; NRC, 2007; Sandoval, 2005).

When teachers and researchers use our pedagogical framework certain characteristics of the current study are important to consider. For example, the context of WKRU. Teachers, scientists and WKRU employees collaborated in project teams to develop comprehensive open IBSE projects for primary school pupils. By means of discussions within the project teams teachers improved their knowledge about important concepts, such as DNA and heredity. Furthermore, they acquired knowledge about the inquiry process and how to support their pupils during this process. As a consequence, the teachers were enabled to support their pupils by addressing specific domains of scientific knowledge within the phases of inquiry. Therefore, to use our pedagogical framework we recommend teachers to collaborate with colleagues and possibly researchers to improve their understanding about the inquiry process and the domains of scientific knowledge to be addressed during this process.

Another consideration is the connection of the domains of scientific knowledge to the introduction phase and conclusion phase. In the introduction phase the teachers paid limited time to the domains of scientific knowledge and in the conclusion phase just a few teachers addressed these domains. As a result, some pupils were unable to present a conclusion that answered their research question. Therefore, we encourage teachers to support their pupils in these inquiry phases.

In the future we will further develop our pedagogical framework to make it more usable for primary school teachers. We will connect tangible tools, i.e. scaffolds, to the framework. These scaffolds are temporary supports that can be removed when pupils are able to conduct their

investigations without the aid of the scaffolds. By means of the scaffolds teachers will be enabled to support their pupils during the process of open inquiry.

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MOTIVATING AND ATTRACTING STUDENTS TO SCIENCE: IDENTIFYING AND IMPLEMENTING GOOD PRACTICE APPROACHES

Karl Schneider¹, Astrid Hensel¹, Constantinos Cartalis², Bara Semerakova³, Bregje van den Brand⁴, Costas Costa⁵, Inese Liepina⁶, Magdalena Machinko-Nagrabecka⁷

¹ University of Cologne - Institute of Geography,

² National and Kapodistrian University of Athens,

³ TEREZA Education Centre,

⁴ SME Advies,

⁵ Cyprus Center for Environmental Research and Education (CY.C.E.R.E.),

⁶ Bernu Vides Skola,

⁷ UNEP/GRID-Warsaw Centre

Abstract: Motivating students to science is of prime importance to address the foreseeable shortage of qualified personnel in this field. Building a positive attitude towards science and encouraging interest in science based on a positive experience of students during their school education is essential in motivating and attracting students to a career in science. In the frame of the project “Motivate and Attract Students to Science (MASS)” funded by the European Union, good practice examples that have a strong potential to motivate and attract students to science are identified, analysed, evaluated and described. In the first phase of the project a survey was conducted among science teachers of primary and secondary schools in partner countries to define requirements for attractive and motivating science lessons. For that purpose a questionnaire was addressed to several thousand respondents in the participating countries (Czech Republic, Cyprus, Germany, Greece, Latvia, Netherlands and Poland) focusing particularly on opportunities and challenges for a) Science for Digital Learners, b) Early Inquiry and c) Low Achievers in science. The results of the survey were used to identify aspects, which are perceived as particularly effective in attracting and motivating students to science. Building on these findings, in a second step the project team identified, collected and documented Good Practice Examples (GPE), which have proven their suitability in the classroom. These GPEs are documented as a catalogue, as manuals and training modules to provide practical support for teachers in science disciplines.

Keywords: Motivation, Science Education, Teaching Practices, Teacher Support

INTRODUCTION

Although whole economies depend on the effectiveness of Science, Technology, Engineering, and Mathematics (STEM) education (Holdren et al. 2010), a severe shortage of qualified personnel pursuing a STEM career is diagnosed for the future (Wang and Degol 2013, Renn et al. 2012). Despite recent increases in the number of graduates in STEM disciplines, the demand exceeds the number of graduates and will continue so in the future (Anger et al. 2014). School education is the foundation for increasing the number of STEM students (Gago EC 2004, EACEA 2011). Thus motivating and attracting students to science is the key to tackle these problems. Good practice examples are needed that have proven their effectiveness to motivate students, yet are also based on sound didactical concepts.

The project “Motivate and Attract Students to Science (MASS)” funded by the European Union aims at identifying, analysing, evaluating and disseminating tools and methods in teaching science at the classroom level. The need to foster STEM education has been recognized by many European countries and has led to national projects and efforts to address this issue. However, coordinated approaches, which aim at sharing and thus benefiting from the

experience in other countries, are rare. MASS aims at establishing a common European platform enabling the participants to inform themselves and share good practice approaches in science education.

Three major challenges were identified which correspond to three target groups:

1. Science for Digital Learners

Today's generation of learners is widely characterized as 'Digital Learners' (Generation Y and Z) (Berk, 2010). The 21st century learner is described as a multitasking, information flow surrounded and technology wise individual. We have to take up the challenge to offer students teaching methods resonating with their way of learning. For that reason MASS project wants to show innovative good practices in using digital tools in the classroom to broaden the 21st century teacher's portfolio of modern methods that are technology connected and digital learner oriented.

2. Early Inquiry

Every child is gifted with inborn creativity and curiosity. If an individual has a natural and meaningful experience with science at a very young age, it is more likely they will respond positively to the complicated learning challenges later on. In this 'curiosity golden age', as Rocard et al. call it (Science Education NOW, 2007), inquiry-based science education (IBSE) proves to be a very effective method. The MASS-project wants to show good practice examples of successful incorporation of the key elements of IBSE to the science classroom practice, with a special focus on primary schools early learners.

3. Low Achievers in Science

There is no specific policy to support low achievers in science in European countries (Science Education in Europe, 2011) but there is an EU Education and Training 2020 Benchmark aiming to decrease the percentage of low achievers in science to the maximum of 15% as the EU average. MASS project aims at investigating the essential driving forces that help low achievers to perform better in and constitute a positive attitude to science.

These three topics were selected for the need and acuteness of the challenge, the innovative potential in these fields and in light of the expertise available in the consortium. This paper presents preliminary results of the project based on the research conducted in the aforementioned seven participating countries.

METHOD

The project aims to provide support for teachers in science education building upon the practitioner's experience and perception of shortcomings of traditional teaching methods. Thus, as a first step factors which teachers experienced or perceived as particularly helpful to attract and motivate students to science education as well as the prerequisites needed for successful science teaching were identified based on a questionnaire distributed to science educators and teachers in primary and secondary schools.

The questionnaire was constructed in view of the fact that teaching and learning approaches are the result of a combination of different factors. Beside competencies (by teaching staff as well as students), curricula, learning content and the didactical-methodical implementations of learning content play essential roles. Against that background a conceptual framework was used for the design of the survey in order to address such different dimensions relevant for the quality of science education at school. The following dimensions were taken into account (see also Jonnaert et al., 2009):

- Actors: the role of students and teachers, and the level of acquaintance of teachers with new tools and methods for science education.

- Educational system: the role of curricula, use of novel techniques in teaching, pedagogical approaches.
- Action framework: what actions need to be promoted to enhance students' motivation in science education?
- Knowledge framework: how does science link to everyday life?
- Evaluation framework: how are teachers, methods and tools evaluated?

The recipients of our survey were mainly teachers. Since the main goal of our research was to identify attractive and motivating approaches, which have shown their effectiveness in practical application in the classroom, teachers are the most reliable instance to judge what accounts for an attractive and effective science education. On the basis of their daily teaching experience and their evaluation competences they are particularly keen observers to figure out today's students' attitude and learning behaviour and they are aware of the potential and limits given especially in light of the underlying learning conditions at schools such as curricula, equipment, available material etc.

In total the study addressed more than 5000 respondents in the participating countries, out of which 700 teachers returned a completed questionnaire.

Based on the analysis of approximately 700 replies, recommendations for approaches suitable for the three thematic areas are described. Afterwards good practice examples were identified which are in accordance with the established recommendations. The procedure to identify, select and disseminate GPE's was as follows:

1. On the basis of criteria such as
 - a. activities are easily traced and understandable,
 - b. approach fits well to the target age group,
 - c. method changed attitudes towards science courses and science,
 - d. observed change in achievement and acquisition of skills,
 - e. raising students' interest in science,
 - f. introduces new pedagogical methods and tools,
 - g. facilitates the interaction between teachers and students and between students,
 - h. can be replicated in other schools in the country/EU,
 - i. products are easily adaptable,
 - j. easy implementation in school curriculum
 each MASS-partner country identified already implemented teaching examples in one's own country which are connected with verifiable positive impact on students' learning effect and motivation.
2. A pool of good practice examples was collected, described and evaluated.
3. Teacher tutorials as well as corresponding training modules for teachers were developed for selected approaches, which provide examples and strategies how to put the recommendations for a good science education into practice.

RESULTS

Results of the survey

The questionnaire consists of an introductory section followed by three modular parts relating to the three target groups of the MASS-project: 1) Science for digital Learners 2) Early Inquiry 3) Low Achievers in Science.

The analysis of the questionnaires led to the following findings:

Introductory section

In the introductory section information on gender, age, teaching experience and teaching subjects of the respondent teachers were recorded, followed by two general questions on science education:

- How would you describe the scientific state of knowledge of your students and their interest in science in general?
- Which factors make scientific teaching lessons interesting for students in your opinion?

The evaluation of answers indicates that “experiments” and “Relationship to own living environment” were regarded as key factors for an attractive science teaching. Figure 1 presents exemplarily the answers of German teachers to the second question, this result is indicative for the results of the other countries as well.

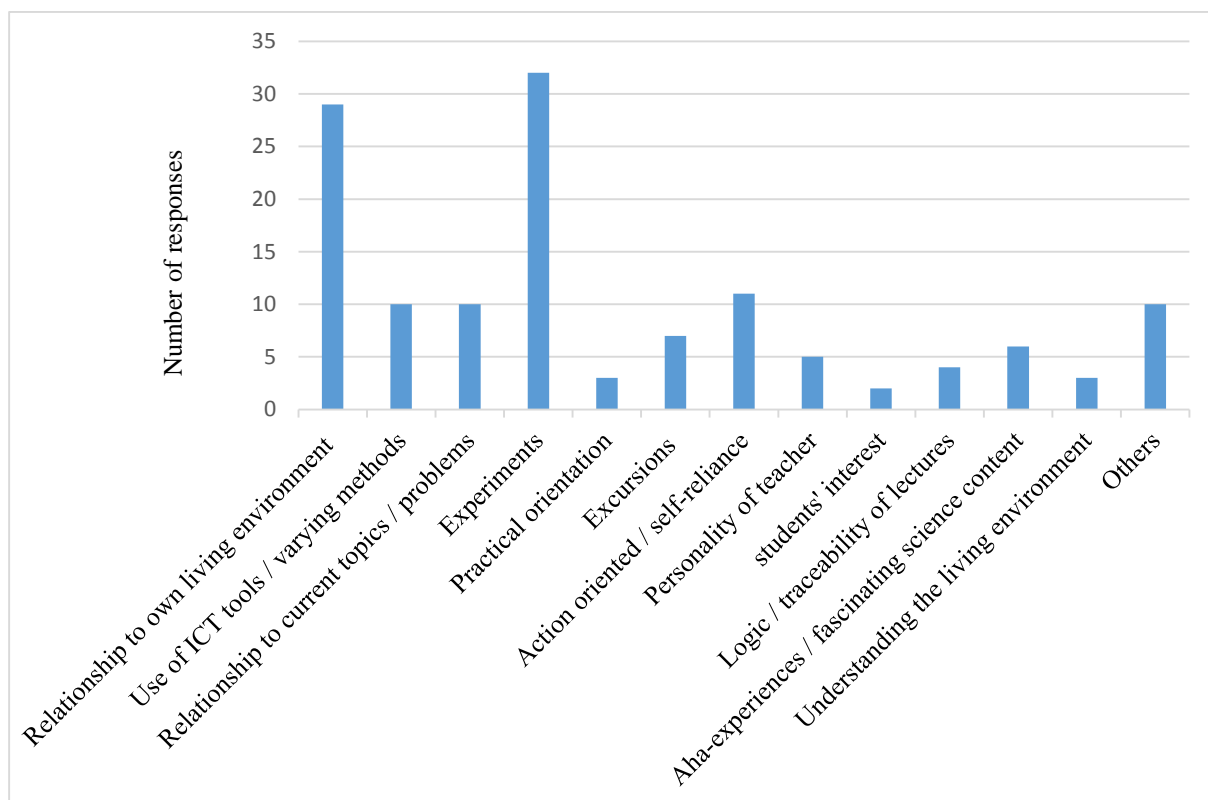


Figure 1. German teachers’ responses on the question “Which factors make scientific teaching lessons interesting for students in your opinion? “ Respondents answered in a free text format and afterwards answers have been assigned to the listed categories (x-axis)

Science for digital learners

This section aimed at understanding the perception and the use of digital tools in today’s classrooms. This goal was addressed by asking (among others):

- How frequently do teachers use digital tools in your classes? What is their experience with regard to the use of digital tools for the attraction of students to science?
- Which specific digital applications do teachers preferably use in the different age groups and teaching phases?
- What are the students’ attitudes with respect to the use of digital tools in science courses?
- What is the teachers’ knowledge, their skills and attitudes in using digital tools?
- What are the limitations that keep teachers from using digital tools?

- What would help the teachers to acquire the digital competence necessary so as to benefit from the use of existing digital tools to make their science course more attractive to students?

The analysis of the replies showed that the vast majority of respondents regularly uses digital tools in their classes. A minority of teachers exhibit a negative attitude towards digital media claiming that practical experience and direct contact with students are more important and that there is too much ICT (Information and Communication Technologies) in schools already. The replies of interviewed teachers reflect that digital tools are mainly used to perform experiments, help students discover basic principles, increase their interest and motivation, and to approach issues that cannot be perceived theoretically. Many teachers use digital tools to introduce a topic in order to attract students' attention and continue with conventional teaching. Inquiry-based learning (IBL) methods and collaborative learning approaches are often combined with using digital tools. Figure 2 shows that teachers find significant added value in using digital tools due to their efficiency in the learning process, their suitability for self-paced learning and the opportunities of a better illustration and visualisation of scientific content. Moreover, the increased motivation resulting from the positive attitude of students towards digital tools is perceived as favourable. The proficiency of teachers in using digital tools depends on the frequency of use as well as their educational background and age range. Many respondents indicate a lack of proficiency. The barriers to use digital tools are similar in all countries, pertaining particularly to a lack of training and support.

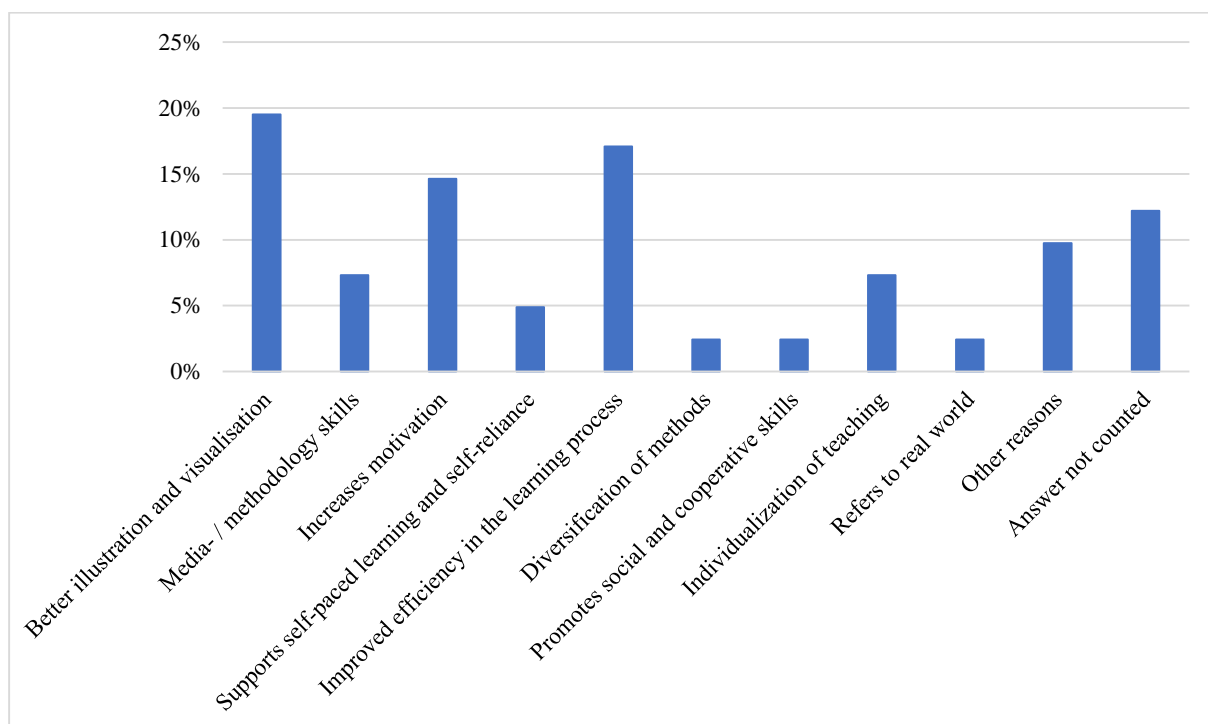


Figure 2. Science teachers were asked to describe the added value of the use of computer applications in their classes. Respondents answered in a free text format and afterwards answers have been assigned to the listed categories (x-axis). The distribution in percentage shown in y-axis reflects the opinions of respondents in Germany. The results were similar in the other European countries.

Early inquiry (EI)

The Early Inquiry section of questionnaire included among others the following questions:

- What do you understand by the concept of “inquiry-based learning”?
- How often do you use inquiry-based approaches in your science lessons?
- Give reasons why you seldom or never use inquiry-based approaches in your science lessons?

- What are the barriers to use in inquiry methods in your lesson?
- Is appropriate teaching material and equipment for inquiry-based methods available for you?
- Advantages and disadvantages of inquiry-based methods

The analysis of the responses lead to the research finding that inquiry-based methods are considered meaningful to increase interest in science. Furthermore it is considered highly supportive for students with learning problems. IBL and traditional deductive approaches are not mutually exclusive and should be combined in science classrooms to accommodate varying levels of students' competences.

But although answers of respondents in general reflect a positive attitude towards inquiry-based methods it becomes obvious that such approaches are only applied rarely by the interviewed teachers. In detail: The vast majority of the respondents (54%) in Germany uses them rarely (on average once per month), 21% of German survey participants even very rarely (once per term) as shown in Figure 3. The same trends are observed in other MASS partner countries.

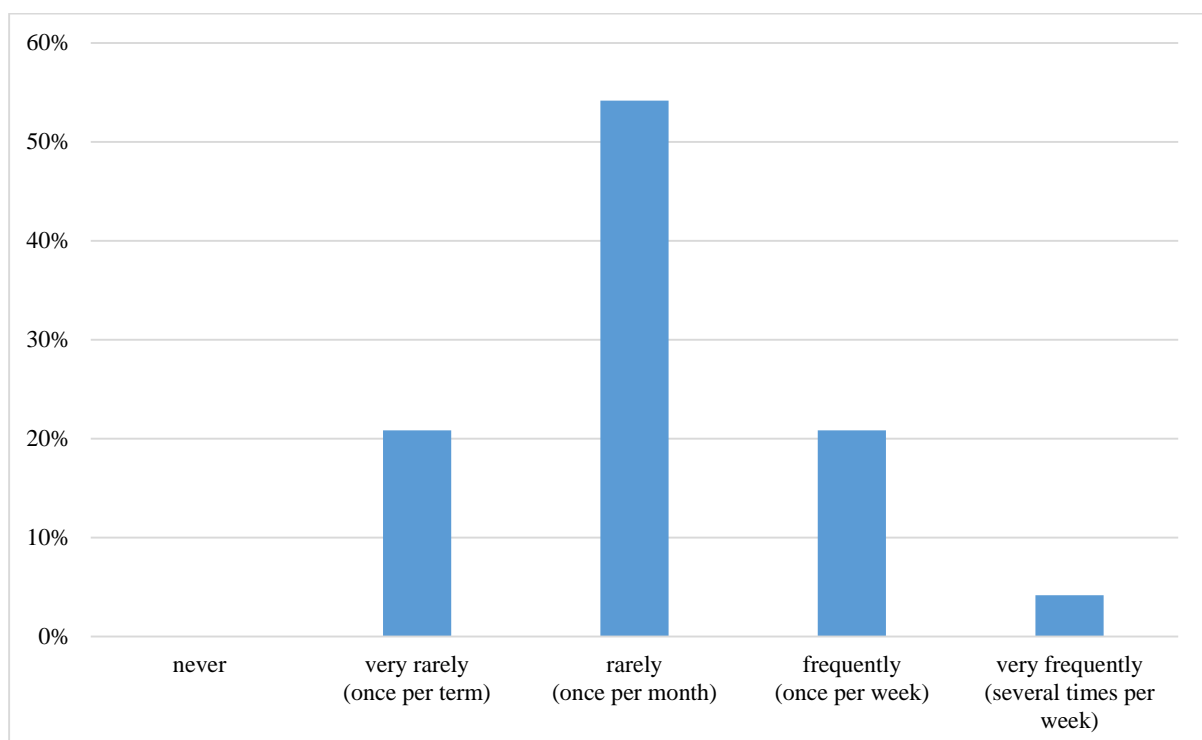


Figure 3. German teachers' responses on the question "How often do you use IBL methods in your classes?" (5 possible answer categories were given).

The given reasons for not using IBL methods are mainly limiting curricular guidelines and lack of time (35%), lack of equipment (30%), lack of students interest (15%) and lack of teachers experience (10%).

Interestingly some respondents indicate a rather vague understanding of IBL approaches. As Figure 4 demonstrates, some teachers relate IBL mainly to group work, project based learning or conducting of experiments in general. This indicates a lack of understanding of the underlying concept of inquiry-based learning.

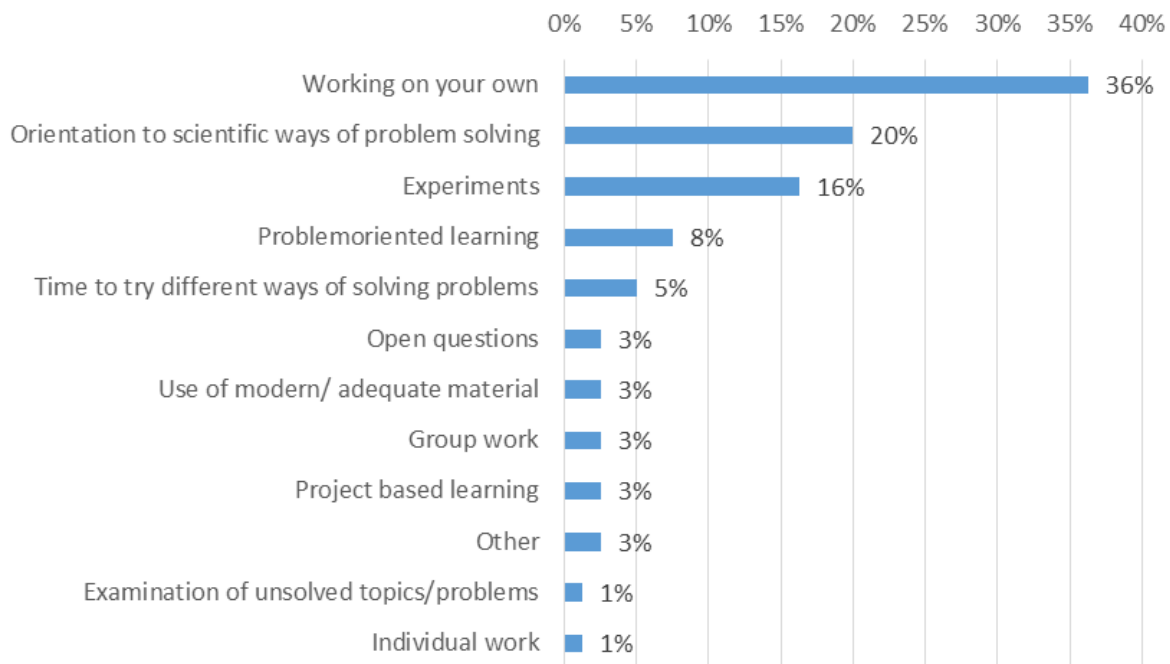


Figure 4. German teachers' responses on the request to describe briefly their conception of the term "inquiry-based learning". The answers were given in free text format and were afterwards assigned to the 12 categories listed.

Low achievers in science

The following questions were asked to specifically address the "Low achievers in science":

- Do you have experience with low achievement in science?
- Why do you think some students do not enjoy science education?
- What approach and which tool can attract low achievement students in science classes according to your experience?
- Do you need training / support so as to apply methods and tools?
- How do you evaluate the familiarity of students with science?
- What would you say is your students' interest in science?

Low achievement of students in science is recorded in all partner countries, although at varying levels due to the different educational systems. The main barriers to students' acquaintance with science in schools are a) the heavily charged curriculum and b) the limited link of science education to daily life. Favoured approaches to attract low achievement students in science classes are: development of a collaborative learning environment, ensuring well-structured science classes with varying levels of difficulty, demonstrating the links to everyday life, showing how science can help mitigate environmental problems.

Recommendations for a more motivating and attractive science education

The questionnaire analysis led to the following recommendations concerning a more attractive and motivating and therefore improved science education in schools:

- Regarding digital tools: Ensure accessibility in schools, organize systematic training and continuous support for teachers, develop teaching and learning materials, provide methodological manuals guiding teachers in using digital tools, disseminate case studies, evaluate approaches.
- Regarding Early Inquiry: Adapt inquiry-based learning approaches at the "early learners" classroom, Reform educational curricula to integrate IBL, re-orient teachers' work load to provide time for preparation of Inquiry-based lessons and materials, reduce classes

size, link IBL to digital tools, organize and populate a common data base of IBL methods, tools and materials, provide training to teachers.

- Regarding low achievers in science: strengthen the integration of science education into the educational system, link science activities to everyday life, integrate across thematic subjects and demonstrate usefulness of science, create a non-competitive atmosphere to avoid drop outs, build school partnerships since social networking fosters students' motivation, provide continuous education for teachers for a) the use of diagnostic tools for early detection of low achievers, b) for ICT and their use and c) for shaping and evaluating science activities.

Action items resulting from these recommendations

Based on the previous results a catalogue of good practice examples was developed that not only describes recommended approaches and their didactical underpinnings, but also gives a clear qualification with respect to the potential of the method to foster students' skills and competence for the different target groups. This pool of Good practice examples is published on the project homepage www.mass4education.eu.

The survey results clearly indicate a demand for freely accessible methodological and material support of teachers as well as a demand for training materials. MASS-project partners have responded to this need by developing teacher manuals for all three projects areas as well as by providing corresponding modules of training which support the exploitation of the manuals and the implementation of suggested activities in classroom.

DISCUSSION AND CONCLUSIONS

In general, the analysis of the survey as well as the evaluation of in-depth interviews conducted with selected teachers clearly showed that teachers support the idea to carve out motivating and attracting ways to impart the sense of science to their students in a sustainable way. Teachers are aware of the fact that the needs of 21st century students differ in certain aspects to former student generations. This requires appropriate adaptations in the classroom. The teacher's role today cannot be defined primarily as the source of knowledge but rather as an advisor and guide in the learning process. The frequently quoted statement "From sage on the stage to guide on the side" (Alison King, 1993) eloquently expresses this change in the teacher's role which is needed not only to capture students attention, but also to connect competence building with the acquisition of content knowledge.

The consensus among interviewed teachers was that digital tools as well as inquiry-based methods have a high potential to offer students a motivating access to science. They are particularly well suited to support an individualised learning progress and in this respect they are well-suited even or especially for low achieving students in science. However, for both approaches (suitable incorporation of digital tools and inquiry-based learning) as well as for the challenge to capture also the attention and curiosity of low achievers, teachers need support in terms of freely accessible learning materials, instruction, suitable equipment and curricula guidelines. Particularly the curricula are perceived as rigid, not allowing enough opportunities for teachers to employ new teaching methods, which may require more time but also provide attractive and motivating approaches to introduce students to the world of science. Against the background that about one-third of factual knowledge is typically forgotten after one year (Custers, 2010) if it is not frequently rehearsed, readjusting the balance between skill development and content knowledge might provide the necessary time needed to utilize activating approaches such as IBL, digital tools and Early Inquiry.

Creating added value to science education by incorporating digital tools and methods in science lessons – conclusions and offers by the MASS project

Based upon the responses describing the students' perspective, the use of digital tools in science lessons will most likely enhance students' motivation. Digital tools are part of their everyday experience, thus connecting particularly well with their habits and interests. Digital tools such as smartphones, tablets and computers in general play an important role in the students' lives. While in private students use them mainly for entertainment and communication, these devices also have a high potential to generate added value in education, particularly in terms of activation, individualization of the learning process and motivation, if they are used in an appropriate manner. For example nowadays a lot of educational apps and serious games are available that can contribute to the learning processes within different subject areas. Furthermore digital networking and collaboration by the implementation of social media platforms can make a substantial contribution to science education. However, there is a challenge of integrating these tools meaningfully in the teaching endeavour.

MASS-project has developed a teacher tutorial as well as a corresponding teacher training module describing a range of digital tools such as educational apps, serious games and social media platforms with regards to their use in the classroom. Step-by-step technical instructions combined with classroom implementation examples framed by didactical concepts have been designed and are available for teachers (www.mass4education.eu). The advantages of the presented digital tools in comparison to conventional teaching methods are discussed and benefits for students' learning process were described such as internal differentiation through adaptation of the degrees of difficulty, student paced learning, integration, activation and encouragement of all students, encouragement of shy students. Nevertheless, possible barriers and difficulties for implementation in classroom are critical indicated.

While the potential of digital tools to motivate students and to offer promising teaching approaches is stressed by the teachers' responses, there is yet another important reason to pay attention to the use of digital tools in science education. In the digital age, where digital devices as well as digital methods have become indispensable for scientific research in terms of scientific measurements, data collecting and data analysis, it is essential to prepare students for these important function and to train both their digital skills as well as their critical reflection on these digital tools. Familiarizing students with the opportunities of digital methods is moreover highly relevant for employment opportunities, to develop citizenship and of course for scientific discoveries.

In this respect the MASS project faces the challenge of a proper implementation of geomedial in science education. In one chapter of the MASS teachers' tutorial on digital tools it is described in detail how geographical information systems (GIS) and satellite remote sensing (SRS) analysing techniques can be incorporated in science lessons with the intention to introduce students to these scientifically relevant digital mapping technologies.

Encouraging teachers to use inquiry-based learning approaches in science lessons for younger students more frequently

In contrast to teacher-transmitted information, inquiry-based learning (IBL) approaches in science education focus on student derived investigations and resulting from this a self-constructed knowledge, which is proved to be more sustainable than memorized facts. The conducted survey has shown that some respondents have a rather vague understanding of IBL approaches since they connect to IBL concept mainly keywords as conducting of experiments or group work.

But IBL approaches go far beyond just performing experiments. IBL-activities cover all stages of the research process: observing natural phenomena, posing research questions, formulating

hypothesis, systematic experimentation, documenting and analysing data, developing and communicating scientific explanations.

Although the results of our survey showed that teachers consider inquiry-based methods as meaningful and attractive, the majority of teachers indicate a rare usage of such approaches in their daily teaching routine. As the two major reasons for this a lack of time as well as a lack of equipment were mentioned. This indicates that teachers are presumably discouraged by the imagination of performing a time intensive, student derived research project with an unforeseeable procedure and outcome and moreover connected with an extensive set of equipment.

The MASS team concluded that in this respect it is important to show examples of practicable ways to incorporate IBL-methods in science lessons which are less time and equipment intensive. Therefore the MASS catalogue of good practice examples presents a comprehensive collection of successful examples tried and tested in several partner countries.

Open inquiry activities in the sense that the research process is completely designed and conducted by students, are only successful, if students are equipped with the skills to conduct their own research study (Yoon et al., 2012). The necessary skills required to do scientific research include (amongst others): a multifaceted way of thinking, the ability to develop strategies, forward-looking thinking, critical thinking, ability to judge, communication skills as well as a highly intrinsic motivation. But all these skills are not innate skills. Especially in the case of early inquiry where younger students, in particular primary school students are addressed we cannot expect mature skills in this respect.

For that purpose MASS recommends the incorporation of single inquiry-based activities to train the corresponding scientific skills. The teacher tutorial on early inquiry is clearly structured in several chapters which each describes a stage of the inquiry circle. It offers the possibility to experience the scientific process step by step thereby training the corresponding scientific skills. For example the chapter “Posing a research question” describes exercises and activities which let students develop a sense of asking meaningful questions by internalizing relevant criteria for questions worthwhile to investigate.

Our tutorial promotes the idea to train in detail the different activities of research process and gives information on ways how to do this. If students and teachers are experienced in the execution of the different stages of the research process and have been effectively trained and therefore developed the necessary skills corresponding to each research step, a successful passing through the whole inquiry cycle becomes possible. Moreover this removes obstacles in teachers’ perception and teachers may feel encouraged to start a bigger open inquiry approach.

The module of training on the topic “early inquiry” aims at a deeper understanding of the inquiry-based learning concept. Once a teacher has internalized the principle of inquiry-based learning he or she may feel encouraged, confident and capable to design individual inquiry-based activities or science lessons on his own which are tailored to the curriculum and the specific needs of his students.

Low achievers in science

Science is broadly perceived as the domain of the talented. But indeed science is a setting where everybody can learn important lessons about the real world. Therefore we are committed to deliver learning through science to every child.

On the basis of the survey the MASS project developed a three level containing strategy for an appealing access to science in particular for low achievers. Considering the level “learning environment and structure of learning process” the positive influences of the following recommendations is shown: Support the creation of a non-competitive atmosphere in the classroom so as to avoid drop outs by low achievers. Provide varying levels of difficulty so as

to limit negative emotions and frustration of the students. Enhance creativity of students through well designed learning modules, which build to each other. Regarding the level “Learning content” MASS’ suggestion is to link scientific content to everyday life. Our selected good practice examples and developed lesson plans explain the relevance of the considered content for students’ own lives and demonstrate the importance of the acquired knowledge in daily life. Moreover they demonstrate that science can solve environmental problems. With respect to the third level “methods and tools” we strongly recommend inquiry-based approaches as well as the use of ICTs (information and communication technology).

If low achievers get the chance to meet science in the described way science education can be an opportunity for every learner to understand the world better.

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EXPLORING THE EFFECTS OF SCIENCE WRITING HEURISTIC APPROACH ON 8TH GRADE STUDENTS' METACOGNITION

Tugce Tuce¹, Jale Cakiroglu¹, Ceren Oztekin¹
Middle East Technical University, Ankara, Turkey

Abstract: The purpose of this study was to explore the effects of Science Writing Heuristic (SWH) approach on middle school students' metacognition. For this purpose, a quasi-experimental research design, the non-equivalent control group post-test only design was used with the aim to compare the experimental and the comparison groups mean difference with respect to dependent variables. 60 eight grade students with a mean age of 14 years in two classes selected from one public school in an urban area. One class was randomly assigned as a treatment group and the other was assigned as a comparison group. Treatment group was instructed by using SWH approach on the other hand; comparison group was instructed with curriculum oriented instruction by using traditional laboratory activities. Metacognitive Awareness Inventory (MAI; Schraw & Dennison, 1994) was used to determine students' metacognition. To investigate the effect of the treatment on the dependent variables One-way Multivariate Analysis of Variance (MANOVA) was utilized. No statistically significant mean difference was found between the two groups regarding MAI scores before the treatment. Post-MAI results revealed that there was a statistically significant mean difference between the experimental and the comparison group, in favor of the experimental group. The treatment method, the science writing heuristic approach, had large effect on declarative knowledge, planning, information management and debugging dimensions of metacognition while had medium effect on monitoring and evaluation dimensions. Differences in procedural knowledge and conditional knowledge dimensions did not reach statistical significance.

Keywords: Science writing heuristic approach, metacognition, argument based inquiry

INTRODUCTION

The National Research Council (NRC, 1996) emphasized inquiry as central to science teaching and learning. Inquiry based science classrooms should provide students not only hands-on laboratory works, but also minds-on activities such as reading, oral discourse and writing as parts of the process of doing science (Wallace, Hand & Prain, 2004). The National Science Foundation (NSF, 2000) published a monograph about inquiry and highlighted the importance of it for science education. Besides, National Research Council stated the significance of inquiry in the Framework for K-12 Science Education as: "...students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined" (NRC Framework, 2012, p. 218). Since 1980, numerous studies have confirmed that different inquiry-based instruction models have positive impacts on teachers and students with various findings. Engaging in an inquiry classroom develops students' creativity and science process, reasoning and critical thinking skills, and also helps students construct better understanding of scientific concepts (Chanlen, 2013). Moreover, students actively involve inquiry-based activities and take ownership of their own learning.

Argument-based inquiry is one of the three main inquiry-based instructional models. Argument-based inquiry focuses the importance of the application of language in science

through argumentation. Argumentation is an important aspect of science education. According to NGSS, student engagement in scientific argumentation leads to students to understand the culture in which scientists live and effects the application of science and engineering on the benefit of society. The Framework for K-12 Science Education underlined the vital role of argumentation as follow:

“The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose”. (NRC Framework, 2012, p. 73)

There are different kinds of approaches and techniques for teaching science within argument-based inquiry. The Science Writing Heuristic (SWH) approach was classified as an immersion argument-based inquiry approach. According to Cavagnetto (2010), the immersion-oriented interventions portrayed argument as a tool not only for the construction and understanding of science principles but also cultural practices of science. Interventions in this orientation were structured to embed argument within student explorations of science principles. Explicitly, argumentation was not viewed something that was made to conclude the inquiry, however, was found during the inquiry as students generated questions, designed experiments, interpreted data, and constructed and defended evidence-based knowledge claims based on their evidence. SWH classrooms encourage students to develop arguments comprised of three components: question, claims, and evidence (Hand, 2008) providing a learning environment in which students are required to conduct inquiry investigations by posing their own questions about the topic under review, collect data, make claims derived from evidence, search what experts say about the topic, and reflect upon the their arguments to see how their ideas have changed.

The SWH has two components which are a teacher template and a student template. The teacher template (Figure 1) consists of a series of recommended activities to engage students in meaningful thinking, writing, reading, and discussion about the laboratory concepts.

Teacher Template

1. Exploration of pre-instruction understanding through individual or group concept mapping
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions
3. Participation in laboratory activity
4. Negotiation phase I-writing personal meanings for laboratory activity (For example, writing journals)
5. Negotiation phase II-sharing and comparing data interpretations in small groups (for example, making a group chart)
6. Negotiation phase III-comparing science ideas to textbooks or other printed resources (For example, writing group notes in response to focus questions)
7. Negotiation phase IV-individual reflection and writing (For example, writing a report or textbook explanation)
8. Exploration of post instruction understanding through concept mapping

Figure 1. The science writing heuristic, Part I: The teacher template

(Source: Keys et al., 1999)

Firstly, eliciting prior knowledge and getting understanding of the scientific context into which the laboratory is situated are expected from teachers. Individual or group concept

mapping is advised for this step. Secondly, pre-laboratory activities such as brainstorming, constructing questions about the topic, or explaining prior knowledge can be planned. Then students attend laboratory investigation which allows for generation of authentic data and outcomes that are unique to that investigation. Also laboratory activities in which the results are not obvious to the students are the best candidates for using the SWH. After that students are permitted to think and write about the personal meanings of their data. This step is followed by students' negotiation about their interpretation with their peers. In this group discussion, students are encouraged to make claims. In negotiation phase III, students may consult authoritative text to compare their ideas. Then students are assigned a writing project to reflect their current understanding about the investigation. In this step diverse writing project such as persuasive essay, research poster, letter or multimedia presentation can be used. Finally, the students are engaged in post-investigation concept mapping for closure of the laboratory activities by the teacher. Depending on the nature of the laboratory investigation and the topic, students may loop back or enter the steps 3 – 6 which are shown in teacher template, as many times as necessary.

As mentioned above, the second component of the SWH is the student template (Figure 2) which used by students throughout the above phases of negotiation.

<u>Student Template</u>
1. Beginning Ideas—What are my questions?
2. Test—What did I do?
3. Observation—What did I see?
4. Claim—What can I claim?
5. Evidence—How do I know? Why am I making these claims?
6. Reading—How do my ideas compare with other ideas?
7. Reflection—How have my ideas changed?

Figure 2. The science writing heuristic, Part II: The student template
(Source: Keys et al., 1999)

Initially, students reveal their science questions related with the laboratory activity to offer an authentic context for inquiry. Then they assess their continuing procedures and observations to relate them to the scientific questions. Although making observations may be similar to traditional laboratory practices, the process of making claims and sustaining them with evidence from their experimental work provides students to interactively construct a deeper understanding (Burke, Greenbowe, and Hand, 2005). After composing their own tentative explanations, students have a chance to compare their claims with the scientifically accepted explanations. In the last step, students reflect on how their scientific ideas have changed throughout the investigation.

Studies conducted during the past 15 years, confirmed that SWH approach has valuable instructional outcomes for science education (Poock, Burke, Greenbowe, & Hand, 2007; Choi, Hand, & Greenbowe, 2013), achievement (Hand et al., 2004; Rivard, 2004; Günel, 2006; Hohenshell & Hand, 2006; Akkuş et al., 2007; Poock et al., 2007; Caukin, 2010; Hasançebi & Günel, 2013) and conceptual understanding (Hohenshell, Liesl, & Hand, 2006; Nam, Choi, & Hand, 2011). Although it can be inferred that the SWH approach positively affect student metacognition (Wallace & Hand, 2004; Akkuş et al., 2007; Choi, 2008 and van Opstal & Daubenmire, 2014), there is a gap in the literature assessing the impact of the SWH approach on students' metacognition. Metacognition, can be defined as an individual's knowledge, control and awareness of his/her learning processes (Thomas, 2002) is an important issue in learning because it manages cognitive activities while selecting, monitoring and evaluating the cognitive tasks (Flavel, 1979). Since science learning draws on many different cognitive

processes, metacognition is inevitably important in science education (Thomas, 2012). In attempt to improve students' metacognition, this study utilized Science Writing Heuristic (SWH) approach.

METHOD

In this study a quasi-experimental research design, the non-equivalent control group post-test only design was utilized to explore the effects of science writing heuristic (SWH) approach on middle school students' metacognition. The sample of the study consisted of a total of 60 eight grade students with a mean age of 14 years in two classes selected from one public school in an urban area. One class was randomly assigned as a treatment group and the other was assigned as a comparison group. There were 31 students (16 girls, 15 boys) in the treatment group while while comparison group was made up there were 29 students (13 girls, 16 boys) The implementation lasted thirteen weeks and included four consecutive science units which are "Sound, Living Things & Energy", "States of Matter & Heat" and "Electricity". Treatment group was instructed by using SWH approach on the other hand; comparison group was instructed with curriculum oriented instruction by using traditional laboratory activities. Students in the comparison group studied the same learning material as those in the treatment group, except they did not use the SWH activities.

In order to determine students' metacognition, Metacognitive Awareness Inventory (MAI; Schraw & Dennison, 1994) was used. It is a 52-item, self-report questionnaire which requires students' responses to the items in a five point Likert scale ranging from strongly disagree to strongly agree. Metacognition was examined in terms of knowledge of cognition (declarative knowledge, procedural knowledge, and conditional knowledge) and regulation of cognition (planning, information management, monitoring, debugging, and evaluating). MAI translated and adapted into Turkish by Sungur and Senler (2009). Turkish version of MAI was initially pilot tested with 200 eight grade students. In order to validate factor structure, confirmatory factor analysis was conducted. All of the fit values confirmed that the factor model of MAI with a good fit. The scale overall produced a Cronbach alpha coefficient of .95. Concerning the internal consistency of the subscales, the Cronbach's alpha coefficients were found to be adequate to conduct further analyses for all of the subscales, specifically, declarative knowledge ($\alpha = .74$), procedural knowledge ($\alpha = .75$), conditional knowledge ($\alpha = .72$), planning ($\alpha = .72$), information management ($\alpha = .78$), monitoring ($\alpha = .79$), debugging ($\alpha = .63$), evaluating ($\alpha = .68$).

RESULTS

To investigate the effect of the treatment on the dependent variables (declarative knowledge, procedural knowledge, conditional knowledge, planning, information management, monitoring, debugging and evaluating) One-way Multivariate Analysis of Variance (MANOVA) The independent variable was mode of instruction. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted for both of the analysis. Results revealed that there was no statistically significant mean difference between experimental and comparison groups with respect to the collective dependent variables, Wilks' $\Lambda = .87$, $F(8,51) = .97$, $p = .469$; $\eta^2 = .13$ before the treatment.

After the treatment, a significant mean difference between the experimental and the comparison groups with respect to collective dependent variables was found, $F(8,51) = 5.92$, $p = .000$; Wilks' $\Lambda = .52$, $\eta^2 = .48$. The multivariate based on Wilk's Λ was strong, 0.48, implying that the magnitude of the difference between the groups was not small. The univariate ANOVAs for the dependent variables were significant ($p < .008$) for declarative knowledge, ($F(1,58) = 24.12$, $p = .000$, $\eta^2 = .29$); planning, ($F(1,58) = 16.88$, $p = .000$, $\eta^2 =$

.23); information management, ($F(1,58) = 22.37, p = .000, \eta^2 = .28$); monitoring, ($F(1,58) = 8.48, p = .005, \eta^2 = .13$); debugging, ($F(1,58) = 18.48, p = .000, \eta^2 = .24$); evaluation, ($F(1,58) = 8.90, p = .004, \eta^2 = .13$) and not significant for procedural knowledge, ($F(1,58) = 4.89, p = .031, \eta^2 = .08$) and conditional knowledge, ($F(1,58) = 6.10, p = .016, \eta^2 = .10$).

An inspection of the mean scores which is shown in Table 1 indicated that treatment group reported slightly higher mean scores in these dimensions than the comparison group.

Table 1 Descriptive Statistics

Treatment Method	SWH Approach		Traditional Instruction	
	M	SD	M	SD
Declarative knowledge	36.29	2.44	32.38	3.65
Procedural knowledge	16.77	2.20	15.17	3.32
Conditional knowledge	21.84	2.15	20.21	2.93
Planning	30.13	2.64	25.93	4.99
Information management	44.32	3.40	38.00	6.56
Monitoring	29.16	3.32	26.07	4.81
Debugging	23.29	1.79	20.62	2.95
Evaluation	25.55	2.85	22.59	4.68

When we examined the mean scores, we found that students in the experimental group had higher mean scores on these dependent measures. The experimental-group students appeared to have more knowledge about themselves as learners, about strategies, and when and how to use these strategies. They also appeared to regulate their cognition at higher levels than did the comparison group students.

DISCUSSION AND CONCLUSION

The findings indicated that SWH approach has positive effects on declarative knowledge and the regulation of cognition dimensions which are planning, information management, monitoring, debugging and evaluation. The result is consistent with the Thomas's claim (2002) that "students' metacognition is socially mediated and that the nature of the classroom learning environment is an important factor influencing the development of students' metacognition". Various researches of science education literature shows student-centered teaching interventions improve learning over traditional teacher-centered teaching interventions. However selecting the most efficacious interventions is a big problem that most of science teachers face (Yoon, Bennett, Mendez & Hand, 2010). SWH can be a good choice for effective science teaching. Moreover this study specifically showed that procedural knowledge and conditional knowledge dimensions were not significantly affected by the implementation of SWH approach. This result may influence framing the pedagogical support that teachers can offer when students are using SWH.

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CONNECTIONIST SCIENCE EDUCATORS: TEACHERS AS MEDIATORS BETWEEN SCIENCE AND YOUNG PEOPLE'S EVERYDAY LIVES

Andrew Howes, Zahra Alijah and Sophina Choudry

University of Manchester

Abstract: Science education fails to engage increasingly large numbers of young people as they move through schooling, particularly in areas of socio-economic disadvantage. This paper offers a critical perspective of science education as a set of practices that mediate between the everyday lives of young people in their communities on the one hand, and scientific practices on the other. This 'connectionist' view of science education entails a recognition of the knowledge, history, culture and practices of young people in their communities, as a lens for making sense of science itself. The paper is a step in the exploration of the question: how do science teachers experience, interpret and mediate connections and disconnections between the practices of science education, and those of science and young people's everyday lives? The exploration is embedded in what we think as 'research from the middle', involving collaborative enquiry and development with eight teachers working in disadvantaged contexts. The 'funds of knowledge' literature (Gonzales et al., 2013) problematises some features of science education practice in the light of our connectionist framework. Two methods are then employed in exploring the question, creating the opportunity for teachers to make sense of their practice. Teachers represented their practice through ranking a set of statements (a Q-sort): they were passionate about science and in their care towards young people, and they sought to engage them in science. Significantly, they saw those young people as having little idea of science outside the science classroom, and that their lived experiences were not very important to their learning in science. Case studies of teachers based on our collaborative research suggest that they perceive significant disconnections between science education and young people's lives. In each case, teachers express surprise and pleasure when considering evidence of the scientific thinking and practice which young people are engaging in within their own everyday practices. The findings suggest that the mediating role of science education is a powerful critical lens worthy of further research.

Keywords: parental involvement; culture; professional development; mediation

INTRODUCTION

There is ongoing concern continues across the EU regarding young people's dispositions away from science education (Archer et al., 2012; Osborne and Dillon, 2008). There are many factors which may be contributing to this failure, such as the tenuous relationship between practices of science and practices of science education, the separation between the life experiences of science teachers and many of the young people they teach, and the dominant discourses which shape young people's ideas about science. In this paper, we reconsider the practice of science teachers in terms of the relationships between science, science education and young people.

1) Science is a body of knowledge, a set of processes or ways of thinking, and a network of practices relating to the physical and natural world. These practices involve, for example, problem solving, questioning, reflective thinking, expert knowledge, processing of information, application of complex concepts, inductive and deductive reasoning (Gallagher, 1991). Such practices are layered into every form of everyday, habitual, mundane practice, including but far from limited to practice in research laboratories. Science is an apparently simple term which arguably disguises more than it reveals. But science is also a field of relationships and positions (Buxton, 2006; Conteh, 2011). Science processes relate ideas,

theories and models on the one hand, and ‘the real world’ on the other (Osborne, 2014 p.192). In framing ideas of connectionist science education, we use the term ‘science practices’ to signify all the ways in which scientific thinking and activity are at work in and on the world.

2) Science education might be similarly understood as a series of practices, involving people, their experiences, curricula, pedagogy, assessment, expectations, predictions, and educational discourses negotiating value and worth. Science education involves teacher education and training, collegiality and competition, a range of institutions and particular ways of ordering time (Buxton, 2006). All of these have been formed historically and in response to socio-cultural and economic developments (Tstasaroni 2006, DeBoer, 1991).

3) Young people’s everyday lives are constituted by a series of practices in particular contexts, shaped by communities and community interests and resources, parents’ and family members’ work and educational experience, discourses of aspiration and alienation, peers and peer interests, and other objective relations of human life including health and illness, economic position, disability, religious and community engagement (Reiss, 2000). Such a perspective unsettles taken-for-granted thinking about young people’s everyday lives, viewing them less as a set of assumed norms and more as a set of practices formed, negotiated and sustained on trajectories through life (Garfinkel, 1964).

In thinking about the nature and purpose of science education, we consider a triangle of relationships between these three sets of practices: of science, of science education, and of the everyday lives of young people (figure 1).

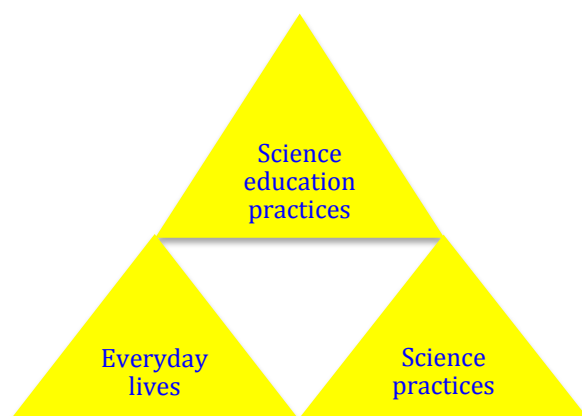


Figure 1 - A representation of the relationships entailed in connectionist science education

In this triangle, each vertex represents a practice or set of practices, while the sides represent the possibilities of relationship and connection, or separation and discontinuity, between these practices. This raises questions about the forms and structures of knowledge, and the modes of participation and exclusion, which are inherent in each. For example, most of everyday, mundane practice is not scientific in character. But these practices are the basis for all the possibilities of scientific thinking, and mundane practice can become scientific at particular moments.

Science education then is less a set of practices with its own purpose and rationale, and more a mediation between the lives of young people in their communities on the one hand, and scientific practices on the other. In this view, science education is a tool to enable young people to use and engage in science and scientific thinking, as a lens for interpreting and acting in their everyday world. Similarly, the knowledge, histories, cultures and practices of young people in their communities are seen as a lens for making sense of science.

By contrast, many conventional views of science education are more narrowly focused. Lemke (2001) argues that ‘we have imagined that the few minutes of the science lesson somehow create an isolated and nearly autonomous learning universe, ignoring the sociocultural reality that students’ beliefs, attitudes, values, and personal identities - all of which are critical to their achievement in science learning - are formed along trajectories that pass only briefly through our classes’ (p. 305).

In this paper, the focus is on the position of the science teacher within this set of relationships. This leads to the research question for this paper: How do teachers experience, interpret and

mediate connections and disconnections between the practices of science education, science and young people's everyday lives?

THEORETICAL PERSPECTIVES

Making sense of science education as mediation entails investigating the relationships between the three different sets of practices, including the practices of young people's everyday lives in communities. By contrast, most definitions of the problem of engagement in science education, and most efforts to address it, disregard many of the dimensions of young people's everyday lives. Those people with less science capital (Archer et al., 2012), have fewer opportunities to recognise science in either their everyday practice or in their imagined future practice.

Here, the 'funds of knowledge' perspective (Gonzales et al., 2013; Barton and Tan, 2009) is very useful. This takes a critical, anthropological gaze towards families and communities that are frequently regarded in school discourse as deficient in some way, if they are noticed at all. The countervailing idea in the funds of knowledge approach is that households and families are rich with scientific thinking and practice, and that in recognizing this and taking account of it, school science discourse can decrease the distance between young people in such contexts and the practice of science. There are some striking examples of this in the science education literature, notably Bouillon and Gomez (2001) who look for 'bridging scaffolds that will provide connected meaning in science learning between students' day-to-day social experiences and science learning' (p. 879), and describe a pedagogical design based on real-world problems that are 'real in the sense that they are current, unsolved, and of consequence-[which] exist in the local community. Shared interests in these problems bring together school and outside-school communities. A funds of knowledge perspective allows consideration of the idea of the social in science education as representing the possibilities of science education practice grounded in young people's trajectories through life: their contextualised and gendered agency in family and community contexts, and their encounters with science through for example the media, leisure, health, housing, work, and transport. These are the possibilities which characterise connectionist science education.

Significantly, these ideas partially contradict some dominant ideas in science education. A widely shared view in science education frames the teacher's role as one of constructing opportunities for children to negotiate the differences between their everyday worlds and the world of science (Driver et al., 1994). In that tradition, 'children's everyday ideas and ways of knowing and talking are largely different from and incompatible with those of science' (Warren et al., 2001, p. 530). The pedagogical value of contrasting 'commonsense' models of phenomena such as light, electricity and forces with scientific models which fit into larger theoretical perspectives is well-attested. But this contrast can lead to a construction of science as standing in opposition to everyday experience, which then simultaneously constructs 'scientists' as experts with a special way of understanding and interacting with the world. Partly as a result of this distinction, the popular image of the scientist in the white coat continues to be evident in the drawings of primary school pupils in many cultures; more significantly, it maintains a view that science is difficult, the preserve of experts, and not for ordinary people.

Buxton (2006) suggests that a valid science teachers' role in 'low-performing, at-risk, urban schools' may be to identify and use teachable moments in which 'authentic science enquiry experiences' (p. 695) become possible. He argues for '... a model of curriculum that attends to issues such as drawing links to family and community and including the flexibility to pursue teachable moments, a model of instruction that attends to issues such as taking inquiry outside and providing the time and resources to engage in problem posing and problem solving' (p.717). We are keen to think with teachers about how they and their students can attend to 'drawing links to family and community' in a way that supports meaningful learning

in science. The acknowledgement of the value of students' funds of knowledge calls for 'flexibility to pursue teachable moments' in science lessons. Furthermore, we see the school science laboratory as problematic to the extent that it reinforces ideas of the separation of science and science education, and so we look towards 'taking inquiry outside... to engage in problem posing and problem solving' – into young people's everyday contexts, rather than towards other special places such as science activity centres.

The discourse of 'authentic science' (ibid.) frames important possibilities for the inclusion of the practices of science into the constructions of science education. It does not, however, address directly the nature of the relationship between science and the everyday. Warren et al. (2001) goes on to review an alternative to the ontological separation of the everyday and the scientific, which 'focuses on understanding the productive conceptual, meta-representational, linguistic, experiential, and epistemological resources students have for advancing their understanding of scientific ideas' (p. 531). This focus on young people's productive resources develops out of the 'funds of knowledge' perspective, and it is a necessary part of a science education which can mediate the participation of young people in science. Young people need this recognition of their agency; they also need the opportunities to develop it in applying science and scientific thinking to their everyday world, and vice versa.

METHODOLOGY

Seeking to learn how teachers experience, interpret and mediate the connections and disconnections between young people's everyday lives, science education and science practices, we constructed a collaborative partnership with high school teachers in relatively disadvantaged contexts, so that we could get close to and participate in their practice. We choose to 'research from the middle', engaging in collaborative enquiry, exploring the possibilities of science education as mediation in practice. In order to highlight this alternative approach in a way that could become meaningful for teachers, we borrowed the term 'connectionist' from mathematics education (Askew et al., 1997) and discussed our collaborative work as 'connectionist science education'.

We considered a wide range of collaborative methods including participative observation in an enquiry group and in science lessons, interviews with teachers and young people, co-teaching, and analysis of the outcomes of classroom processes. The enquiry group became central; the place in which we talked pedagogy together, where pedagogy was evident as 'the observable act of teaching together with its attendant discourse of educational theories, values, evidence and justifications' (Alexander, 2009, p. 916), the what and the why of teaching, developed through a phased process of exploration, interpretation, utilization and reflection. Together, we began to describe the existing links and particularly discontinuities between their science classrooms and young people's broader knowledge and experience. The group developed pedagogical tools including participative photography (Howes and Miles, 2014), participative mapping and daily timelines, aiming to create opportunities for dialogue in the science classroom in which young people could draw on and link with their everyday practices in families, peer groups and communities.

Sameera is the subject of a case study presented later in the paper. She created an exercise involving photography, which encouraged young people to take pictures of science in everyday life, at home for example, or in their local park. She was surprised by the depth of engagement that the young people demonstrated: "This picture is a picture of some grass! It is in my garden. I think this picture is science as it is very amazing ... I took this picture as it is science and it shows how insects live in it. Grass is kind of relevant to me as it is beautiful and makes me wonder about the great things within it" (pupil account). Another teacher in the collaborative group reflected on the transfer of knowledge in the classroom: "Because the context is so intimate to students' lives, the ultimate aim is that students introduce these

connections themselves during class discussion or the learning takes place by talking directly to the relevant people or involving the relevant place” (teacher interview).

We developed a set of pictorial ‘job cards’ for use with young people and parents, inviting them to sort out the jobs which they felt required no science, basic science and advanced science. This generated rich dialogue about the practices of science. Through another set of cards, we began to explore with young people their fascination with science as well as their disinterest in science education. Our expectations were that these activities would enrich existing pedagogical approaches and relationships, probably rooted in a rich dialogic approach to increasing engagement in science and scientific thinking. These are areas of the research which will be explored in more detail in other papers, but these experiences also contributed to the writing of teacher case studies in this paper.

A significant influence was the opportunity to engage with practices of science education that teachers were already developing in response to the problem of lack of engagement by young people. One approach was through adaptation of the curriculum, with teachers selecting and elaborating contexts for learning science that they thought likely to appeal to young people. A process of trial and error is common, perhaps because teachers have few ways of predicting whether a particular context will in fact be motivating for particular groups of young people. But the fact that this is a common practice presented possibilities for research around these explorative approaches, again with teachers, young people and parents. This approach requires a flexible, responsive research process, for example developing tools and approaches to take advantage of emerging opportunities for dialogue around particular curriculum initiatives being developed by teachers. This created a strong sense of solidarity in the collaborative team, and provided opportunities for learning about the way teachers positioned themselves. We quickly found that we were working with teachers who were already engaged in activities with young people that entailed mediation, though they had not reflected on their practice in this way, and though they had a limited vocabulary to bring to such reflection. Naming and identifying the features of this practice made apparent contradictions between these activities and other features of teachers’ current practice, explaining some of the significant tensions that teachers acknowledged as they positioned themselves in practice.

Having seen informally how teachers were already engaging with features of mediating science education, and also how much they were struggling with this, we used the triangle of related sets of practices as the theoretical framework to inform two specific approaches to addressing these questions. Q-methodology using factor analysis to construct groups of people who represent aspects of their experience in similar ways (Stainton-Rogers, 1995). We constructed a pack of statements (a ‘concourse’) each of which related to one or more of the three sets of practices of science education, science and young people’s everyday lives, drawing on statements from relevant literature, and from discussions in our collaborative meetings. We then invited eight of those teachers to sort the cards, placing the statements on a scale of 1-9, according to how well the statement represented their own position. When this was completed, teachers were also asked to comment on their placing of any statements that had stood out for them.

Case study was our other approach. Cases were selected to address variation in the context of science education within the school, including norms of collegial and innovative practice and degrees of alignment with senior staff. Two case studies are presented in this paper in which the teacher’s position is the focus (Stake and Savolainen, 1995). These have been constructed with reference to the framework, drawing on our experience of working with teachers in their respective schools, in monthly collaborative enquiry meetings, and on their comments in relation to the Q sort. The framework serves to highlight aspects of teachers’ beliefs, background, assumptions and practice which extend our understanding of connectionist science education.

FINDINGS

Q methodology

The quantitative element of Q methodology uses factor analysis to identify different groups of people who respond to the statements in similar ways, so it was surprising to discover that the eight teachers who sorted the forty-eight statements did so in a way that was very similar to each other, and that there was therefore only one ‘factor’ of people resulting from their sorts. In the diagram below, this factor is shown, with the high ranking on the right representing the statements that were most strongly agreed with and vice versa. We also included some statements, which closely represent our emerging ideas of constructivist science education, and these are marked in red.

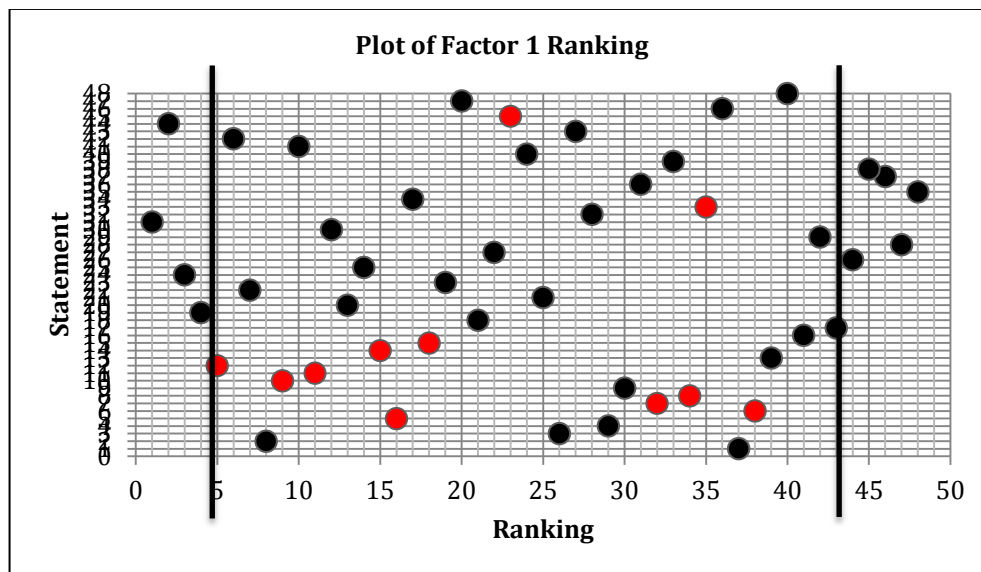


Figure 2 – Factor analysis of Q Sort statements represented in terms of ranking

Representing the statements in terms of ranking has allowed us to, firstly, interpret the statements that Factor 1 teachers most agreed with, and least agreed with; and, secondly, identify key connectionist science statements (highlighted in red on figure 2) vis-à-vis the triangle of connectionist science (see figure 1).

Factor 1 summary: These teachers are passionate about science and in their care towards young people, and they want to engage them in science. Significantly, they see those young people as having little idea of science outside the science classroom. All eight teachers were positively associated with this factor.

Table 1. Q sort statements with which Factor 1 teachers most agreed

Agree (most agreed first)	Disagree (most disagreed first)
17. It is important to keep a sense of the big picture of myself as a science teacher	12. Young people have a clear idea what science is outside the science classroom
26. I am passionate about helping young people to learn science	19. I can't afford to have lessons that are failures
28. I am passionate about science (e.g. physics, biology or chemistry...)	24. Teachers' careers are decided by their year 11 results
35. Building a relationship with young people matters to me	31. I am a teacher because people in my family have been teachers.
37. When I have finished teaching them I want my pupils to feel that I cared about them	44. There is little point in teaching science to young people when it has no relevance to their lives

Agree (most agreed first)**Disagree (most disagreed first)**

38. I would like the young people that I teach to remember the feeling of being excited about science

Factor 1, science education and science: Factor 1 science teachers appear to be reflective of their role as a science teacher: “it is important to keep a sense of the big picture of myself as a science teacher” (S17 – Rank 43); which appears to be deep rooted in their own passion for science: “I am passionate about science (e.g. physics, biology or chemistry...)” (S28 – Rank 47).

Factor 1, science education and young people: Factor 1 science teachers’ passion about science appears to be linked to their passion for influencing young people: “I am passionate about helping young people to learn science” (S26 – Rank 44). “I would like the young people that I teach to remember the feeling of being excited about science” (S38 – Rank 45). At the same time, there is a level of empathy involved in the process of evaluating themselves their role as a science teacher: “building a relationship with young people matters to me” (S35 – Rank 48) and “when I have finished teaching them I want my pupils to feel that I cared about them” (S37 – Rank 46). There is less agreement with the idea of embedding their own lived experiences in science lessons to engage with science as evident in the connectionist science statement: “I use my own life experience to make science relevant to young people” (S33 – Rank 35).

Factor 1 perspective on school: Finally, these science teachers disagree that their school culture sets a value only on their test results: They strongly disagree that “teachers’ careers are decided by their year 11 results” (S24 – Rank 3) and that “I can’t afford to have lessons that are failures” (S19 – Rank 4).

Case studies of science teachers and connectionist science education

The case studies focus on two teachers, Katie and Sameera. Both took part in the Q sort and therefore were identified with Factor 1 above, broadly affirming the value of science to young people in the future, whilst seeing little connection with young people’s current lived experience.

Katie is strongly committed to teaching, to getting young people engaging in science. She has been teaching for fifteen years, much of this in a relatively small, inclusive high school in the city, with the majority of young people coming from relatively disadvantaged communities. Katie lives locally, but unlike many of her pupils, her ethnicity is white British, from a middle-class background. She is a parent herself, with two children at primary school, and works part-time. For some years she has been an advanced skills teacher, in a role which has included in-service training alongside teachers in her own school and others in the city. She is committed to working with young people, and expresses little interest in management roles that would take her away from active science teaching.

Katie, science education and science: Katie’s upbringing was one in which ‘finding out stuff’ was valued; she gives the example of conversations on walks in the countryside with her parents. In a year out on placement with a wildlife trust, she was surprised that the other students there ‘had no idea!... and you just assume that how you grew up is how everyone else grew up’. ‘I just naturally want to find out some stuff’. Her dad was ‘sciency’; her mum very practically minded, an English teacher in an inner city school in a neighbouring city, ‘loved it’. Referring to people involved in education, she says ‘I think everybody wants to make a difference’.

Curiosity and a search for new ideas motivates Katie’s engagement with research in science education. She is usually involved in several projects, engaging in thinking about how to

improve the processes of science education and particularly willing to do so where there is a direct benefit in terms of resources for the school, for example in the shape of access to question banks.

Katie, science education and young people: Katie has a very clear idea about the purpose and importance of relating *positively* with students. ‘You have got to have the relationship with the kids to make a difference. You can know your science. You can know everything that theory teaches you. But if you don’t have that positive relationship, it’s a waste of your time... I want them to be comfortable with me, so they can ask me the questions... I think that it is important’ (Q sort interview).

Katie also has a clear purpose in learning about students and in getting to know them. ‘I don’t want to sit there and talk to them at every break. But I would like there to be interactions. You’ve got to say hello to every child...’ She will connect lessons to her personal history if she can, but ‘you don’t want to be one of the teachers that only talk about themselves. And again it’s about knowing the kids.’ She recognizes that not all kids are the same, and that some don’t particularly want to be known by the teacher. She warms to the idea of being ‘students of our students’. ‘To me it means that you should be watching them and interacting with them. In that case it should be [ranked most highly]... There are things I do in different ways with different children’ (Q sort interview).

In characterizing the key features of working with children from disadvantaged backgrounds, Katie continues to avoid generalisations, and she is strengthened in this by her teaching and observation of many different students. She sees young people as naturally inquisitive: ‘I think they are, unless things in life have knocked it out of them... I think humans are naturally inquisitive. But I think it is harder for some of us.’ There is a strong sense here of the tough reality of some children’s lives, and what this does to them as learners. But that does not mean that including students from socially disadvantaged background necessarily requires a specific approach. ‘It depends on the students really. They can be from such a background but be very engaged’ (Q sort interview).

Katie wants some aspects of science to affect young people emotionally, beyond their knowing and understanding science, though their learning is always a reference point. ‘I want them to care... I would like them to feel some sort of emotional impact on certain things. If you can tie it into memory then you can tie into their memory. As long as you can make it in a positive way, because you can also do it in a negative way. But if you could do that in a positive way then that can help them with their learning’ (Q sort interview).

Katie and connectionist science: The idea that young people may have a lot more to bring to science than teachers typically perceive, even if the young people themselves don’t know it, is interesting to Katie, but it is not something that she has thought much about before. She is very ready to talk about the way her own curiosity, her childhood and parental influence have affected the way she engages in the world – she speaks very coherently about these things, with a strong sense of her own ‘funds of knowledge’. However, when one of her classes took part in a lesson thinking about the science required for various jobs, Katie expressed surprise at what some of the young people revealed, such as one girl who described herself as a seamstress, with intentions to do a textiles degree, and with a recognition that this was an area which involved a lot of science. Another girl talked about going to the bakers’ shop and spending time talking about baking, finding out about their work and what it involved, and here Katie recognized herself and her own strong sense of curiosity: ‘that’s what I do, I’m always asking questions, at the hairdressers for example’. There was a sense of astonishment that this might something that these young people were engaging in too.

Katie’s school, from Katie’s perspective: Katie has a strong sense of her school as a good school, with hard-working teachers doing a good job, with a diverse group of mostly wonderful and interesting young people, some of whom can be challenging to work with. She

is confident in the support that she has in the school, partly because of the length of her experience. Can she afford to have lessons that are failures? Certainly. ‘And that might be partly because I am in a school where I know I’m trusted. I’m long enough in it to know that it will be ok to try things...to be fair I have always felt like I was supported to take risks...’. From Katie’s point of view, therefore, there is a high degree of congruence between her practice and what is valued in her school.

In summary, Katie has a clear purpose as a teacher in wanting young people to engage in science education, and to learn to see the value of science; but the focus on the science which those young people know and engage in outside the classroom is unusual for her, and a source of considerable surprise.

Sameera is also a committed science teacher, working long hours outside of school time to plan lessons and projects to engage and enthuse young people. Though she had considered teaching as a potential career whilst undertaking her higher and further education, Sameera came into the profession following a career change; she felt teaching would give her the opportunity to make a positive difference to young people and to inspire them to learn about science. Neither of her parents were teachers and, though education was valued by them, she is the first in her immediate family to become a teacher.

Sameera is now entering her sixth year of teaching and her teaching career to date has been in the school she joined as a newly qualified teacher. She considers the school to be very similar to the one she attended as a pupil: single sex in an area with relatively high levels of deprivation and a significant proportion of pupils from minority ethnic backgrounds. Like some of the pupils she teaches, Sameera came to the UK as a child, speaking very little English. She comes from a minority ethnic background which is underrepresented in the UK teaching profession. Sameera has taken on responsibilities within the science department and is currently responsible for developing projects and the curriculum for age eleven and twelve.

Sameera, science education and science: Sameera is interested in learning and trying out new approaches to teaching science. She attends science teacher networks and continuing professional development sessions to develop her practice. In our collaborative enquiry meetings, Sameera has explored ideas other teachers have piloted, reflecting upon them, and considering how she might try them out in her school context and with which of her teaching groups.

Though pupils’ learning of and engagement in science is important to her, in articulating the aim and outcome of activities, it is the engagement and enthusing of pupils that comes across strongly when Sameera speaks and in the Q sort she undertook. Within the science department, Sameera has had varying responsibilities which have given her the opportunity to develop science and STEM related projects and activities. One included leading on “science week”: a week of lunchtime activities to coincide with British Science Week, which is an initiative of the British Science Association, aiming to raise the profile of STEM subjects and careers. With her colleagues, Sameera planned an “open house” over lunchtimes with themed workshops and activities taking place in science classrooms and other locations around the school, including the school hall and canteen. Older pupils acted as “science buskers” to market science week and to deliver short taster activities to draw younger pupils. There were also external visitors and speakers, notably STEM ambassadors and a physics presentation.

Interestingly, many of these individual activities were already within the science department’s schemes of work. However, their inclusion in a circus offering choice and autonomy, together with the hands-on practical element, was felt by Sameera and her colleagues to have made them more engaging for pupils. Sameera felt “the atmosphere was pure enthusiasm”. The manner of delivery too, with teachers and older pupil engaging with individuals and small groups was also felt to have been a factor.

Sameera, science education and young people: Sameera identifies very strongly with the pupils she teaches. Her school has a high proportion of pupils from minority ethnic backgrounds with a significant number of new arrivals – pupils of a similar background to her. She talks of her pupils as individuals and reflects on their barriers to learning as well as recognising their interests and their talents, including those outside of science. Building a relationship with the young people she teaches is very important to Sameera, in order for them to feel cared for and enjoy science. In our meetings, reflecting on activities other teachers have undertaken, Sameera probes to learn about the age and attainment range of the groups and considers how the activity might be adapted to suit them.

Sameera, science education and connectionist science: Sameera uses her own life experience to make the science she is teaching relevant to pupils. Within her teaching, she considers groups of pupils rather than individuals, drawing upon experiences young people will be likely to share, such as a lack of confidence in mathematics, or knowledge of particular celebrities. She feels it is important young people see more clearly how important science is in their lives but feels they need scaffolding to do it. An example of her efforts to provide this is mentioned earlier in this paper.

Sameera's school from Sameera's perspective: Sameera has felt challenged by her school context: the governance and management has changed over the last few years and staff are subject to regular performance monitoring. School priorities have also shifted and she feels the emphasis is very much on a view of pupil attainment based on external examination outcomes. At times, this makes her reflect on her position as a science teacher: How is she viewed as a science teacher by the school and by pupils? What is the purpose of teaching science to pupils? Is she a good teacher? In planning projects, Sameera considers how they will be received by the senior leadership team in the school and how they could support priorities the school might have. She felt the school Science Week raised the profile of science at the school, creating “a big buzz”.

In summary, Sameera has a clear purpose as a teacher in getting alongside pupils with whom she can identify strongly, and thereby helping them to see more clearly the value and opportunities that science presents in their lives, and she seeks out opportunities to do this. The idea that young people may already have considerable knowledge and engagement in science outside school is one that Sameera has begun to explore further, but she perceives limitations in the form of curriculum and attainment priorities.

The comparison between these cases is helpful. Looked at through the triangular lens of the connectionist science education framework, Katie and Sameera position themselves in subtly different ways. As science educators, they are both committed to fostering young people's engagement in science education. Katie starts from the educational value of scientific practices such as enquiry-based learning, aiming to draw young people into engaging with a scientific view of the world. Sameera identifies firstly with young people, and seeks experiences in science education that will inspire them and herself. Katie finds it strange when other science graduates have little knowledge to draw on to make sense of the world, but she is also surprised to discover that some of the young people in her classes think scientifically just as she herself does – that they have the beginnings of a scientific world view. These features of young people are not so surprising to Sameera, but she acknowledges barriers to focusing more systematically on this, in the current school context.

Both Katie and Sameera, at this point, are intrigued with the idea that science and scientific practices are woven through the lives and communities of the young people, unarticulated and underexplored. These differences may seem slight. Arguably though, they represent different routes towards that might lead further towards connectionist science education.

DISCUSSION

How do teachers experience, interpret and mediate connections and disconnections between the practices of science education, science and young people's everyday lives? The evidence of both the Q sort and the case studies is that teachers perceive significant disconnections between science education and young people's lives, but that these differences are interpreted differently depending on the teacher's orientation to the practices of science education with which they are engaging. It may be that teachers who align themselves with those existing practices tend to overlook the potential connections with young people's everyday lives, whereas those who are more critical of current practice are more ready to see the educational value in mediating those connections.

In each case, though, teachers express surprise and pleasure when considering evidence of the scientific thinking and practice which young people are engaging in within their own everyday practices. We may infer from this surprise that, despite a curricular focus on how science works and about science as a series of interlinked processes, these teachers do not routinely expect that young people will come to know what it means for them to do science, or act scientifically in their everyday lives. This interpretation is strengthened by the negative response of related Q sort statements.

However, there are indications in their talk that these teachers recognize and relate to the possibilities of a more connectionist orientation to their practice and to knowledge in their classroom. We speculate that where the teacher moves from a position of authority and assumptions about the lives of young people, to acknowledging his or her own lack of knowledge of the practices in which young people engage and have knowledge, the possibility may emerge for dialogue around the value and relevance of science and scientific thinking to young people, and that in this dialogue, the mediating role of science education may begin to be realized.

This paper has introduced a critical framework which challenges some embedded aspects of current practice in science education, and used that framework to look critically at the way teachers of science think about their practice. In doing so, it has addressed one of many important aspects of this perspective, and raised many questions which demand further research. The authors warmly invite comment and reflection on the paper in the light of others' experience and thinking, and will be delighted to engage in dialogue regarding any of the issues raised here.

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CHEMISTRY TEACHERS' PROFESSIONAL KNOWLEDGE, CLASSROOM ACTION AND STUDENTS' LEARNING

Holger Tröger¹, Elke Sumfleth¹ & Oliver Tepner²

¹University of Duisburg-Essen, Germany

²University of Regensburg, Germany

Abstract: Teachers' professional knowledge is examined by several national and international studies (e.g. COACTIV, MT-21) and is seen as a fundamental precondition for improved students' learning. Though research indicates a connection between teachers' professional knowledge and their students' learning achievement, research lacks findings on the connection between teachers' professional knowledge, their actual classroom action and students' learning outcome. The presented study focuses on the relationship between German secondary school chemistry teachers' professional knowledge on the handling of technical language and their actual handling of technical language in class as well as their students' learning achievement. The study's findings indicate a significant connection between aspects of teachers' professional knowledge and their students' learning outcome. Moreover, first qualitative analyses show that teachers in classes with high learning achievement and teachers in classes with low learning achievement differ strongly in their handling of technical language. This proceeding depicts the study's theoretical framework, methodology and results regarding teachers' professional knowledge, their acting in class and the learning outcome of their students in detail and ends with an outlook about pending focus areas of investigation.

Keywords: professional knowledge, chemistry, classroom action, students' learning, technical language

INTRODUCTION

Research on quality of instruction is an important facet of recent educational research (Abell, 2007; Arnold, 2007; Clausen, 2002). Teaching is considered as a highly complex activity and several different models were developed to describe the connection between different elements of teaching, as there are teachers' and students' characteristics, general conditions of teaching and classes as well as students' learning achievement and motivation (Bauer, 2011; Baumert et al., 2010; Berry, Friedrichsen, & Loughran, 2015).

Though these models vary in complexity and focus, teachers' characteristics are regarded as of fundamental importance for students' learning outcome (Krauss et al., 2008). Findings of recent studies on teachers' professional knowledge (e.g. COACTIV or MT-21) hypothesize a connection between teachers' professional knowledge and students' learning achievement (Kunter et al., 2013).

THEORETICAL FRAMEWORK

Professional Knowledge

Following Shulman's (1987) initial operationalization, teachers' professional knowledge comprises at least seven dimensions: *content knowledge* (1), *general pedagogical knowledge*

(2), *curriculum knowledge* (3), *pedagogical content knowledge* (4), *knowledge of learners and their characteristics* (5), *knowledge of educational contexts* (6) and *knowledge of educational ends, purposes, and values* (7) (Shulman, 1987). Recent research focuses on three distinct dimensions of professional knowledge:

- Pedagogical Knowledge (PK)
- Content Knowledge (CK)
- Pedagogical Content Knowledge (PCK)

Still following Shulman's description of pedagogical knowledge (PK), this type of knowledge comprises strategies and principles of classroom management and classroom organization, and is generally regarded as not subject specific (König, Blömeke, Paine, Schmidt, & Hsieh, 2011; Shulman, 1987).

Content knowledge (CK) comprises the in-depth knowledge of a particular subjects' content (Kleickmann et al., 2012; Riese & Reinhold, 2012). Findings in recent studies in mathematics education indicate that a teacher's repertoire of actions and explanations connects to the depth and range of their CK (Kunter et al., 2013).

Over time, PCK was described by many approaches and though there is no consistent conceptualization of PCK (Abell, 2007, 2008; Berry et al., 2015; Park & Oliver, 2007) it is considered important for teaching. Several national and international studies focus on and discuss the meaning of teachers' PCK for teaching (Park, Jang, Chen, & Jung, 2010) and the development of PCK (Abell, Rogers, Hanuscin, Lee, & Gagnon, 2009; de Jong & van Driel, 2005). PCK can be described in various models like the model of teacher professional knowledge and skill (TPK&S) which integrates the construct PCK in the very complex structure of teaching and learning (Gess-Newsome, 2015). Research operationalizes and models PCK in various forms and nuances. General professional knowledge and topic-specific professional knowledge (TSPK) can be seen as a knowledge base and are quite static. In a recent PCK summit, the conception of PCK was extended to take classroom action into account. Personal PCK can be described as “the *knowledge* of, *reasoning* behind, and *planning* for teaching a particular *topic* in a particular *way* for a particular *purpose* to particular students for enhanced *student outcomes* (Reflection on Action, Explicit)” (Gess-Newsome, 2015, p. 36). Personal PCK&S is operationalized as “the *act of teaching* a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes* (Reflection in Action, Tacit or Explicit)” (Gess-Newsome, 2015, p. 36).

This definition suggests that teachers' PCK has manifold aspects and facets. As PCK is a highly complex construct, any investigation requires an emphasis on certain aspects of PCK. In this study, the focus is on pedagogical content knowledge about technical language (PCK_{TL}).

Technical Languages

Language is of central importance for learning. Language is not only the primary medium of interpersonal communication used to transfer information like thoughts, beliefs or knowledge (Bußmann, 2002; Eunson, 2012) but it is also deeply connected to cognition and thinking (Childs, Markic, & Ryan, 2015). Technical languages (TL) are an artificial form of language (Bußmann, 2002) used with the specific purpose to communicate on a subject-specific level (Grucza, 2012; Roelcke, 2005; Schmölder-Eibinger, 2013). Although technical languages are not clearly defined in detail, common characteristics of technical languages can be derived. Technical languages have a specific lexis, commonly known by the expression *technical terms* (Özcan, 2013; Taber, 2015) and more complex syntactic structures as well as more compositions and nominalizations are used than in everyday language (Schmölder-Eibinger, 2013). In chemistry, technical language is of central importance for a meaningful

communication as it also comprises formal and pictorial elements of language like symbolic expressions (e.g. structural formulas, chemical equations). These are considered as of fundamental importance to communicate about chemistry (Childs et al., 2015; Taber, 2015).

Students' knowledge of and proficiency in language and technical language are deeply and inseparably connected to their subject learning as well as their development of scientific literacy (Özcan, 2013; Taber, 2015; Yore, 2012; Yore, Bisanz, & Hand, 2003) which are regarded as central aims of present science education. Deficiencies in this field might lead to the development of misconceptions or inadequate representations of scientific concepts (Barke, 2015; Taber, 2015).

Teachers have to deal with their own and their students' technical language in class as it is an integral component of subject-specific teaching. Therefore, handling of technical language is seen as an important aspect of PCK in this study.

RESEARCH OBJECTIVE

Studies in the field of educational research attend to the connection between teachers' professional knowledge and their students' learning outcome as well as the development of teachers' or student teachers' PCK. However, research lacks findings on the connection between teachers' professional knowledge, their actual action in class and their students' learning. This study is part of the joint research project ProwiN (**P**rofessions**w**issen in den **N**atur**w**issenschaften) [Professional Knowledge in Sciences]. The joint research project explores teachers' professional knowledge and its connection to students' achievement and classroom action in biology, chemistry, and physics. This study's objective is to shed light on the aforementioned desideratum. It focuses on the investigation of the connection between chemistry teachers' subject-specific professional knowledge regarding technical language, their classroom action and students' learning achievement.

RESEARCH DESIGN

In this study, chemistry classes of German secondary school teachers (German *Gymnasium*) in North Rhine-Westphalia and Bavaria took part. The lessons cover the topic *atomic structure and periodic table of the elements*. In general, this topic is taught in the 8th grade at German *Gymnasium*.

There are four points of measurement (MSP) in order to collect all required data (see figure 1).

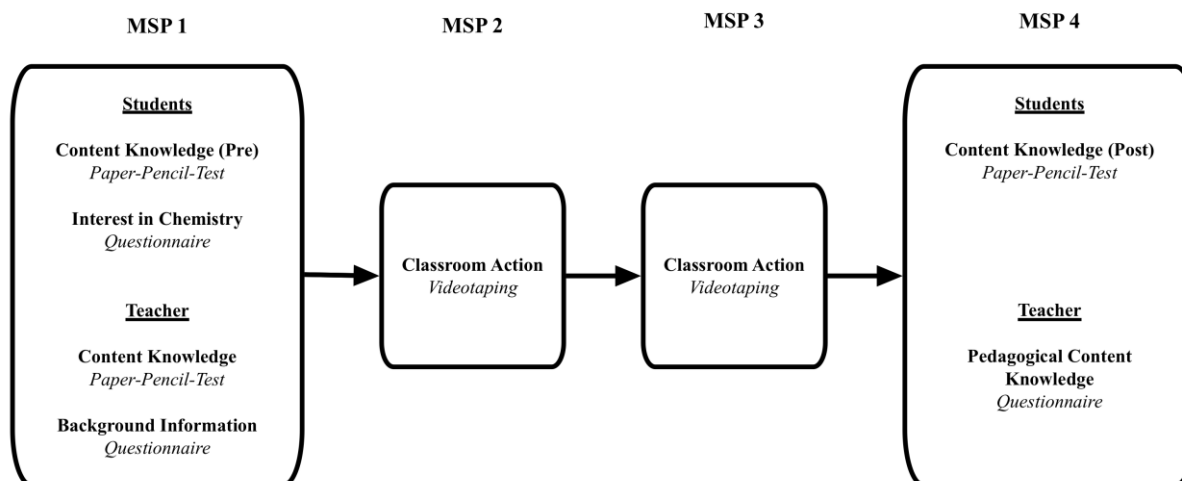


Figure 1: Course of testings

The first testing had taken place before the teaching sequence on the aforementioned topic began. During the first testing, students' prior content knowledge and their general interest in chemistry as well as teachers' CK and background information were ascertained. Then, two successive lessons were videotaped. At the end of the teaching sequence, students' post content knowledge, and teachers' pedagogical content knowledge regarding the handling of technical language (PCK_{TL}) were assessed.

TEST INSTRUMENTS

Students' learning achievement was examined using a multiple-choice-single-select test in a pre-post-design. The applied test was specifically developed to measure students' content knowledge regarding the topic *atomic structure and the periodic table of the elements* and evaluated in a pilot study. The piloted test comprised 40 items in two test booklets using a multi-matrix-design and answered by a total of 149 students. The items were analyzed using Rasch measurement. Evaluation shows good values for item (.92) and person (.77) reliability. 30 items were selected based on item discrimination ($> .75$), item fit ($.80 < MNSQ < 1.2$) and criteria of validity and were included in the final test instrument.

Students' interest in chemistry was assessed by a questionnaire. Students answered to several statements on a 7-point Likert scale (subscales e.g. regarding their personal interest in chemistry, the perceived importance of chemistry for their persona future).

Teachers' CK was examined using an evaluated multiple-choice-single-select test (Tepner & Dollny, 2014). The test-instrument was carefully developed in a previous study (Dollny, 2011) and validated in a subsequent assessment. This test comprised 29 items covering distinct aspects of the subject's content taught in school.

Teachers' PCK_{TL} was assessed by a questionnaire which was specifically developed (Strübe, Tröger, Tepner, & Sumfleth, 2014). Fifteen items have been constructed and evaluated in a pilot study. Each item comprised a fictional dialogue between a student teacher and one or more of his students and four statements describing possibilities of action or judgements of the dialogue. All dialogues were constructed based on theoretical assumptions and video-data of a prior study. The participants were asked to rate each statement on a Likert scale from 1 (very appropriate) to 6 (not appropriate at all). All ratings were treated as answers to a dichotomous knowledge test and scored on the basis of expert ratings. Nine university professors for chemistry education answered the same statements as the teachers. Teachers were scored based on their accordance with the experts' opinion on the statement. Experts showed a good agreement on the statements. In consensus with expert notes and discussions, statements showing less satisfying item characteristics were adapted, and twelve items were selected to form the final test-instrument.

Teachers' classroom action regarding their handling of technical language was examined using a highly inferent coding manual. The coding manual was developed based on theory and video-data at hand and comprised categories regarding the technical language and content-related (e.g. correctness of utterance or content-related complexity of the turn). Subcategories regarding the language include e.g. the language related complexity (form of lexis, composition of syntactic structure) and the inducement for the utterance. Subcategories regarding the content comprises the content related complexity and the correctness of the utterance. Using these categories, 10 videos of chemistry lessons from a prior video-project were rated by two trained raters. Each utterance of the teacher or his students was rated on the basis of the coding manual. Evaluation shows a very good interrater reliability (on average $\kappa = .88$), ranging from nearly perfect ($\kappa = 1.0$) to good agreement ($\kappa = .72$). Based on experts' opinion and theoretical assumptions, the manual can be regarded as valid. Additionally, an all over rating questionnaire has been developed based on the coding manual. The questionnaire

reflects the coding categories in several statements which are rated by trained raters on a 5-point Likert scale. This allows a time-efficient qualitative analysis of classroom action regarding the handling of technical language.

RESULTS

All reported performance measures were analyzed using Rasch measurement, taking item difficulty into account. According to this, e.g. results for teachers' CK do not reflect their raw scores but their ability in CK. Raw scores highly correlate to Rasch scaled measurements (e.g. CK: $r = .97$, $p < .001$). Since Rasch measurement takes varying item difficulty and the test-subjects' ability into account, it is considered as an appropriate way to measure ability (Boone, Staver, & Yale, 2014). It should be mentioned that a negative score for a person's ability does not reflect 'negative knowledge' but indicates a lower than 50% probability for the person to answer an item of average difficulty correctly (Boone et al., 2014).

Teachers

In this study, 28 chemistry teachers participated ($\varnothing = 50\%$). The teachers are, on average, between 42 and 43 years old and have spent between 12 and 13 years in school service ($SD = 11.52$). The teachers show very good content knowledge and variance in their PCK_{TL}. Comparing this study's teacher sample (ProwiN 2 sample) to the prior study's and subsequent assessment's sample of teachers of the same school form (validation sample) indicate that the ProwiN 2 teachers have significantly better CK than the validation sample $t(201) = 3.32$, $p < .001$, $g = 1.08$. This fact might explain the mediocre person reliability of the CK test items. The reliability of the PCK_{TL} test is good (see table 1).

Table 1. Teachers' CK and PCK_{TL}

<i>Scale</i>	<i>N_{Teachers}</i>	<i>N_{Items}</i>	<i>Ability (M)</i>	<i>SD</i>	<i>Person Reliability</i>	<i>Item Reliability</i>
CK	28	29	2.62	1.35	.58	.58
PCK _{TL}	28	35	1.42	1.14	.78	.84

Students

Reported results are based on the complete datasets of 764 students ($\varnothing = 49.1\%$). The 764 students come from 34 classes taught by the aforementioned 28 teachers and are, on average, between 13 and 14 years old. Students show a significant development of their personal ability regarding their content knowledge on the topic *atomic structure and periodic table of the elements* with a strong effect size $t(763) = 36.14$, $p < .001$, $d = 1.4$. This reflects their actual development in content knowledge (see table 2). Students show only little prior knowledge, explaining the poor person reliability of the pre test. Post test person reliability is good.

Table 2. Students development of content knowledge

<i>Scale</i>	<i>N_{Students}</i>	<i>N_{Items}</i>	<i>Ability (M)</i>	<i>SD</i>	<i>Person Reliability</i>	<i>Item Reliability</i>
Pre test	764	30	-.77	.60	.40	.97
Post test	764	30	.27	.90	.73	.99

Regression analyses indicate that students' prior knowledge is the strongest predictor for students' learning, followed by their interest in chemistry. Teachers' CK and their PCK_{TL} each contribute to variance explanation (see table 3). Under consideration of all four aforementioned predictors, a total variance of 26% can be explained.

Table 3. Predictors for students' learning achievement

	<i>B</i>	<i>SE</i>	β	<i>R</i> ²	ΔR^2	<i>p</i>
<i>Students' variables</i>						
Prior knowledge	.63	.05	.43	.22	-	< .001
Interest in chemistry	.01	.00	.24	.02	.02	< .001
<i>Teacher variables</i>						
CK	.07	.02	.25	.01	.01	< .001
PCK _{TL}	.08	.03	.26	.01	.01	.004

Comparing analyses of students' learning achievement of students with high and low prior knowledge show a distinct change in the variables predictive power and amount of explained variance. For this purpose, the student sample was differentiated by their prior knowledge. Only the 25% with the highest and the 25% with the lowest prior knowledge make up the data basis for following analyses. For students with low prior ability, 24% of variance can be explained while for students with high prior ability, explained variance decreases remarkably to 13%. Analyses also show that the significance and predictive power of each predictor changes considerably (see figure 2). Results for students with low prior ability retain the results of the entire sample; prior knowledge remains the strongest predictor followed by interest in chemistry. Findings indicate that students with low prior knowledge benefit more from teachers' CK and PCK_{TL} than students with high prior knowledge. For students with high prior knowledge, of the reported four predictors, only their knowledge itself and their interest in chemistry are significant predictors and even equally strong.

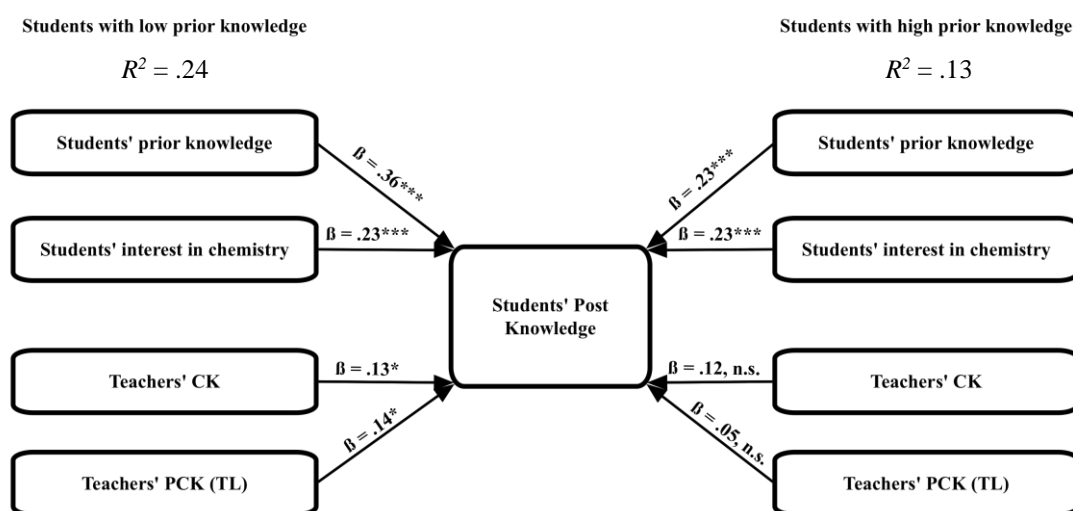


Figure 2: Predictors for students' post knowledge differentiated by prior knowledge

Teachers' Acting in Class

Analyses of teachers' acting in class have not been finished. The reported results of qualitative analyses focus on extreme classes: the class with the highest post knowledge (class A) and the class with the lowest post knowledge (class B). Both classes are taught by trained chemistry teachers (teacher A and teacher B) and comprise 20 students each. Qualitative analysis is conducted on the basis of the aforementioned evaluated overall rating questionnaire and covers both videotaped lessons of each teacher. Though their PCK_{TL} does not differ strongly, analysis of videotaped lessons shows a distinct difference in their actual handling of technical language in class. Both teachers show a strong use of technical terms,

complex syntactical structures when giving monologue or explanations and rather simple syntactical structures with ellipses and other characteristics which can be expected in spoken language when confronted with spontaneous situations (e.g. questions). Although both teachers show a strong use of technical terms, teacher A uses fewer and more specific technical terms while teacher B shows a high frequency and variance of technical terms. Teacher A fosters a more dialogic structure in class. Confronted with spontaneous situations, teacher B reacts faster than teacher A but uses technical terms less precise. In contrary, teacher A takes more time to answer and uses his technical language very precise. In addition to that, teacher A pays attention to his students' correct use of technical language while teacher B barely reacts to inadequate utterances.

SUMMARY AND PERSPECTIVES

Teachers' professional knowledge is subject to educational research and regarded as an important aspect of quality of instruction. National and international studies indicate a positive connection of teachers' professional knowledge and students' learning outcome albeit most studies focus on theoretical aspects of PCK and types of knowledge. Teaching is a highly complex and dynamic activity which makes it necessary to consider teachers' actual acting in class when examining the connection of teacher traits and students' learning.

This study employs paper-pencil-tests, questionnaires and video-analyses to investigate the connection between teachers' content knowledge (CK), pedagogical content knowledge regarding technical language (PCK_{TL}), teachers' acting in class and students' learning achievement in chemistry. The sample consists of 28 German secondary school chemistry teachers teaching the topic *atomic structure and the periodic table of the elements* in 8 grade.

Findings show a significant development in students' content knowledge and confirm a significant relevance of teachers' CK and PCK_{TL} for students' learning outcome. Especially students with low prior knowledge benefit from high teacher CK and PCK_{TL}. Preliminary results of video-analyses indicate a disparity between teachers' theoretical professional knowledge and their actual acting in class. Albeit teachers' theoretical knowledge about handling of technical language differs only slightly for the entire sample, teachers of the classes with the highest and lowest learning outcome show a divergent handling of technical language in class and their students' learning achievement varied strongly.

Further investigations will focus on the quantitative analyses of classroom action in order to consider teachers actual acting in an explanation model for students' learning outcome. Classroom action could mediate between teachers' CK and PCK_{TL} students' learning achievement. The study's final findings might contribute to a better understanding of the relevance of technical languages for teaching and learning and the complex construct of PCK. In addition, the connection between PCK, teachers' actual acting in class and students' learning is examined and findings might contribute to this complex and foremost important relation for teaching.

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AN EXPERIENCE OF ELICITED INQUIRY ELUCIDATING THE ELECTRON TRANSPORT IN SEMICONDUCTOR CRYSTALS

Dominique Persano-Adorno¹, Nicola Pizzolato¹, Claudio Fazio¹ and Onofrio R. Battaglia¹

¹Physics Education Research Group

Dipartimento di Fisica e Chimica, Università di Palermo (Italia)

Viale delle Scienze, Ed.18

90128 Palermo (Italy)

Abstract: In this study we report the results of an inquiry-driven learning path experienced by a sample of 10 electronic engineering students, engaged to investigate the electron transport in semiconductors. The undergraduates were first instructed by following a lecture-based class on condensed matter physics and then involved into an inquiry based path of simulative explorations. The students were invited by two instructors to explore the electron dynamics in a semiconductor bulk by means of Monte Carlo simulations. The students, working in group, had to design their own procedure of exploration, as expected in a traditional guided inquiry. But they experienced several difficulties on planning and carrying out a meaningful sequence of simulative experiments, many times coming to a standstill. At this stage, the two instructors actively participated to the students' debate on the physics governing the observed phenomena, never providing exhaustive explanations to the students, but giving comments and hints, sometimes expressly incorrect, but effective to stimulate students' reasoning and activating a proficient scientific inquiry. The relation between this teaching intervention and student cognitive and affective development has been investigated by methods of discourse and behaviour analysis, as well as by the analysis of a student motivation/satisfaction inventory. The elicited inquiry stimulated the students to follow a question-driven path of exploration, starting from the validation of the model of electron dynamics within the semiconductor, up to performing reasoned inquiries about the observed characteristic of charge transport. Our results show that the stimulated activation of the inquiry process constitutes an efficient teaching/learning approach both to effectively engage students into an active learning and, at the same time, to clarify important experimental and technological aspects of semiconductor science, representing a viable example of integration of a traditional lecture-based teaching approach with effective learning strategies.

Keywords: Inquiry-based approach, Electron transport properties in semiconductors, Monte Carlo simulation

INTRODUCTION

In the last decades, there has been a considerable interest in indium phosphide (InP) semiconductor because of its application in many optoelectronic and photonic devices (Katz, 1992). For this reason, a deeper understanding of the peculiarities of the electron transport dynamics in InP structures is becoming essential in undergraduate education in electronic engineering as well as in semiconductor science.

A traditional lecture-based instruction of solid state physics provides the students with a theoretical background regarding the band structure, the concept of effective mass and the basic phonon-induced scattering mechanisms. However, an effective and efficient engineering instruction, should be able to train the students towards a full comprehension of the

fundamental concepts of semiconductor science but, at the same time, strengthen their reasoning skills and transversal abilities (Borrego & Bernhard, 2011). In this context, inquiry-based education represents the natural framework to develop opportunities of learning science concepts in terms of an active construction of meaningful knowledge and stimulate high levels of critical thinking skills (Llewellyn 2002; Wei et al. 2014). A pure theoretical approach is hardly successful in teaching physics, because any mental construction (Greca & Moreira, 2000) is based on experience and students rarely fully understand a theory, even if currently accepted, if it is left far from a direct experimentation (Pizzolato et al., 2014). Unfortunately, the setup of real experiments on semiconductors is not easily available in most university laboratory for large numbers of students. At this regard, numerical simulation, being considered a practice in between theory and experiment, can represent a valid alternative (Capizzo et al, 2008; Li et al, 2012).

In this paper we present and discuss the results coming from an inquiry-based learning path experienced by engineering undergraduates in order to study the electron transport dynamics via Monte Carlo (MC) simulations in InP semiconductor bulks. This work does not focus on student modelling abilities, but on the sequence of reasoned explorations, carried out within a scaffolding environment aimed at stimulating an effective understanding of the physics concepts underlying the complex world of semiconductor electronics. In traditional guided inquiry (Banchi & Bell, 2008) the instructor provides the students with only the research questions, and the students design the procedures to find reasonable answers and/or test the resulting explanations. However, when the students have to investigate the physics involved at microscopic scale, they often show several difficulties on planning and carrying out a meaningful sequence of explorations. As a consequence, it could become necessary to increase the level of instructor's guidance, never providing exhaustive explanations to the students, but giving comments and hints effective to stimulate students' reasoning and activating a proficient scientific inquiry (elicited guided-inquiry).

Finally, this learning path can represent a powerful instrument for educators introducing young undergraduates to the efficacy of MC simulations to inquiry a physical system where the theoretical processes are well understood, but analytical methods of investigation still provide only approximate results.

METHOD

A sample of 10 students in electronic engineering at the Laboratory of Condensed Matter Physics of the Department of Physics and Chemistry, University of Palermo, Italy, participated in this study. These students, who attended more than 80% of the traditional course on condensed matter physics, were involved into an inquiry-based learning path concerning the investigation of the carrier dynamics in InP semiconductor crystal via MC simulations. This method, being one of the most powerful simulative techniques, allows to numerically simulate the charge transport in semiconductor structures, beyond the quasi-equilibrium approximations (Moglestue, 1993). This technique, representing a space-time continuous solution of the transport equations, is suitable for studying both the steady state and the dynamic characteristic of a device (Persano-Adorno et al, 2001). It accounts for the main details of band structure, scattering processes and heating effects, specific device design and material parameters. Students scientist-like activities were supported by two teachers having more than 15 years of expertise in the field of scientific research and on teaching physics at both high-school and University level courses.

A series of inquiry-driven simulations performed by the students with the aim of elucidating the role of important physical quantities, such as the lattice temperature, effective mass, doping concentration, intra-intervalley interactions, on the carrier dynamics inside the

semiconductor bulk are reported. Since this study reports a research-like experience about semiconductor transport properties carried out by engineering undergraduates within two successive frameworks of inquiry-based instruction (traditional-guided and elicited), does not need the comparison with an external control group. In order to explore the student learning process from the widest point of view, we collected data both during the initial phase of traditional guided inquiry and after the succeeding inquiry with the intervention of instructors' elicitation.

The relation between the teaching intervention and student's cognitive development was investigated by methods of discourse and behaviour analysis. Videotaped data, analyzed on the basis of an in-context search for keywords or phrases and specific aspects of the student's behaviour (speech and gesture events), gave evidence of the enhancement of the cognitive processes during the stimulated inquiry learning path. In particular, this study reports the results coming from a detailed analysis of speech events. A deeper investigation including the analysis of students' gestures is still in progress and those results will be reported in a forthcoming paper. Information about the student affective development and motivation to learn was achieved by using a questionnaire based on the Intrinsic Motivation Inventory (Vos et al., 2011), with specific items adapted to our study. The student satisfaction was measured investigating the appreciation of material, the appreciation of computer-based instruction and the usefulness of the learning path.

RESULTS

The task requested to our students was to explore the electron dynamics in a semiconductor bulk of InP by means of MC simulations, with a particular address to the role of the effective mass, intervalley and intravalley scattering, crystal impurities, and lattice temperature on carrier dynamics. The general problem driving students' questioning deals with the exploration of concrete chances of improving the electron transport dynamics, in terms of an increase of the signal speed, i.e. carrier velocity, with respect to the lower achievable cost of maintaining, i.e. the driving electric power.

The students, working in groups, had to design their own procedure of exploration, as expected in a traditional guided inquiry. Although our students had first received a traditional lecture-based instruction on semiconductor physics and attended a seminar about the use of MC procedures, when engaged into this learning path, they experienced several difficulties on planning and carrying out a meaningful sequence of simulative experiments, many times coming to a standstill. At this stage, two instructors actively participated to the students' work by contributing to debate on the physics governing the charge dynamics, never providing exhaustive explanations to the students, but providing comments and hints, sometimes expressly incorrect, but effective to stimulate students' reasoning, and activating a proficient scientific inquiry.

The active participation of the instructors to the discussion (as peers) activated student scientific inquiry through the onset of an effective questioning: after the initial model validation, the stimulated inquiry learning path was articulated in three successive phases. Each one started from a reasoned question and included a set of simulative experiments whose results were explicative at some level of understanding and, at the same time, boosting the learners' thinking with further questions to address by a deeper scientific inquiry.

Before starting to use a model developed by others, our students tested its validity, by comparing its computational outcomes with experimental data reported in literature. In this preliminary phase the students carefully checked the conditions under which real experiments were carried out (lattice temperature, carrier density, etc), in order to set up the correct parameters, first focusing their attention on the capacity of their simulated data to closely

reproduce the corresponding experimental values, while leaving the effective understanding of the physics beyond their findings to a subsequent explanatory phase. In this phase, the instructors drove students' inquiry towards the exploration of those model parameters which can be opportunely tuned to achieve their goal.

In particular, the students performed the validation process by investigating how the average electron drift velocity at lattice temperature $T=300$ K changes as a function of the driving electric field. In Figure 1 we show the experimental data collected by Glover et al. (1972) (triangles), Nielsen (1972) (diamonds) and Hayes (1974) (asterisks) as compared with the student numerical findings (green squared), obtained by averaging the ensemble means of the electron drift velocity over the total temporal length of the simulation. The error bars overlying the green squared symbols represent the standard deviation of the ensemble means of the electron drift velocity. The agreement between the numerical and experimental data shown in Figure 1 was considered sufficiently satisfactory over the whole range of investigated values of electric field, providing the requested validation of the Monte Carlo model.

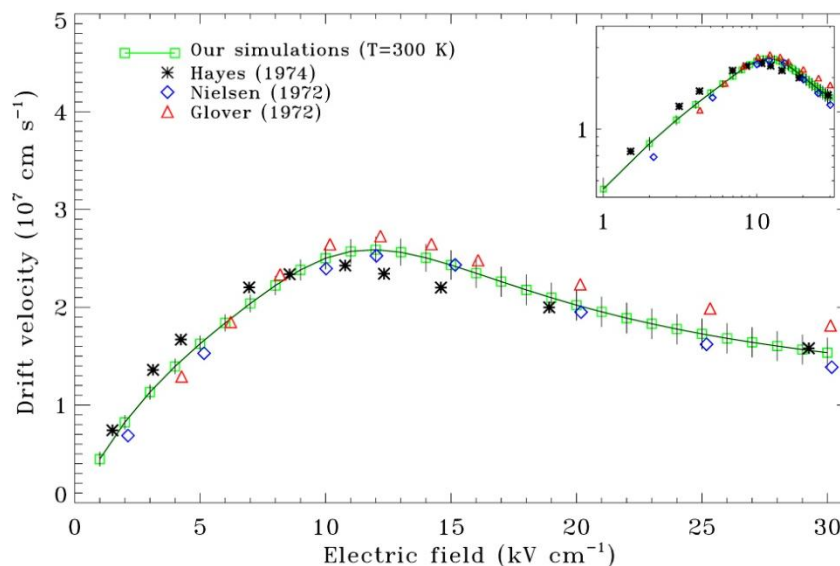


Figure 1. Comparison between simulations (green squared) and experimental data collected from by Glover et al. (1972) (triangles), Nielsen (1972) (diamonds) and Hayes (1974) (asterisks). The vertical lines overlying on the green squared symbols provide the statistical errors associated to the computed average values of the drift velocity. The inset shows the comparison between the experimental and simulated data on a log-log scale.

Phase 1: Which physical quantities affect the velocity-field characteristic?

The first question driving students' inquiry about the electron dynamics within the InP semiconductor regarded the observed features of the electron velocity-field characteristic (Panel (a) of Figure 2). The students found the presence of a nonlinear velocity-field characteristic, with an initial increasing phase of the electron drift velocity, followed by a maximum (at ~ 10 kV/cm) and a subsequent region, characterized by a decreasing velocity for higher values of the electric field. This result represented a surprise for the students, who probably expected to find the well known ohmic behaviour. In effect, in the low field region the velocity-field dependence resembles the familiar Ohm's law, while a significant deviation from it is clearly evident at stronger electric fields. The instructors stimulated the students to

inquiry about this phenomenon, in order to address the physical reason beneath the observed decrement of the electron drift velocity.

After a stimulating discussion, the students focused their attention on the electron energy (Panel (b) of Figure 2). They found that in the range 1-8 kV/cm, the mean energy increases slowly up to ~ 0.1 eV; higher driving fields cause a rapid enhancement of the electron energy up to a saturation regime at about 0.4 eV. The gathered data were twofold surprising for the students who firstly expected that the mean energy always follows the electron velocity characteristic and consequently drop as the mean velocity does, and secondly they did not expect a saturation of the energy levels, but eventually an increase for higher driving fields. A discussion was stimulated by the instructors on how this phenomenon could be physically explained and, in particular, they questioned: “What really happen to the electron ensemble at higher electric fields?”

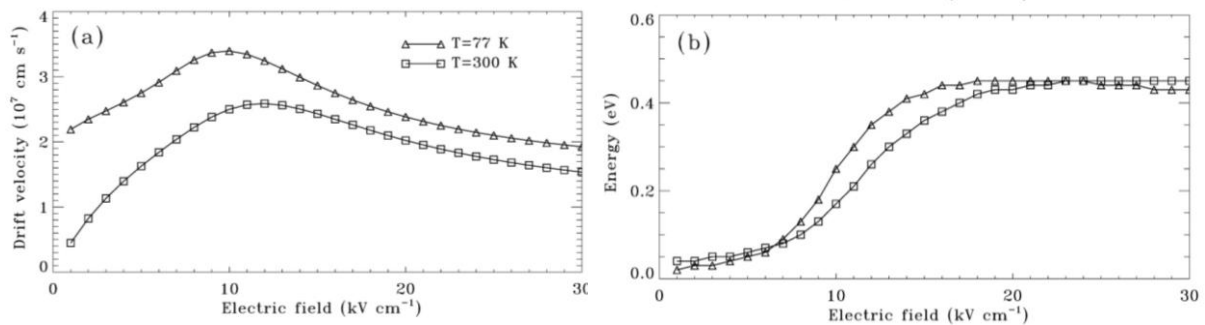


Figure 2. Averages of drift velocity (a) and kinetic energy (b) as a function of the driving electric field, for MC simulations of electron transport in InP with impurity density $n=10^{13} \text{ cm}^{-3}$, at lattice temperatures $T=77 \text{ K}$ (triangles) and 300 K (squares), respectively.

At theoretical level, the students know that electrons moving within a semiconductor may occupy different valleys, depending on their energy, and they have already studied that electrons in different valleys are characterized by different effective masses. The application of an electric field causes the electrons to cease to be in equilibrium with the crystal lattice and increase their energy until they have the possibility to transfer from the Γ -valley to the higher energy valleys (L- and X-valleys), where the effective mass is greater (heavy electrons). At this stage, in order to confirm the electron transfer, the students decided to investigate the electron occupancy in each valley as a function of the electric field and noted that electrons start to populate the higher valleys when the electric field amplitude reaches values greater than about 10 kV/cm, the same value characterizing the maximum of the velocity-field characteristic. This finding supported the importance of taking into account the effective mass of charge carriers and the fundamental role played by scattering events, finally responsible for intervalley transitions.

Phase 2: How important is the role played by the effective mass?

A reasoned inquiry guided the learners through a deeper exploration of the relevance of the role played by the effective mass of drifting electrons. The students carried out different simulations and compared the results obtained by using the three-valley model (green triangles) and those coming from the single-valley (Γ) model (red squares, “1v”), in which the electron transitions to higher energy valleys are inhibited. Moreover, they investigated the effects of considering all electrons having the same mass, but this time equal to the average value among the effective masses for different valleys.

The single-valley data of the electron drift velocity (red squares in both panels of Figure 3) describe an increasing trend in the whole range of investigated values of electric field, without showing the maximum observed in the results coming from running a multi-valley model. By forcing all electrons to remain within the lower energy band, our students had the opportunity to confirm that the decrease of the electron drift velocity observed at fields greater than 10 kV cm^{-1} is ascribed to the electron transitions up to higher energy valleys. In fact, for field amplitudes lower than the threshold field (Gunn field), where all the electrons are in the Γ valley, the two plots coincide, but in the single-valley case, for values of the electric field greater than the Gunn field, the drift velocity of electrons increases monotonically.

The velocity-field characteristic obtained at both 77 and 300 K considering all electrons having the same mass, but this time equal to the average value among the effective masses for different valleys (crosses and points in panels of Figure 3) shows a similar trend, increasing linearly. In this case the students did not have the possibility to appreciate divergences between the multi-valley and the single-valley model.

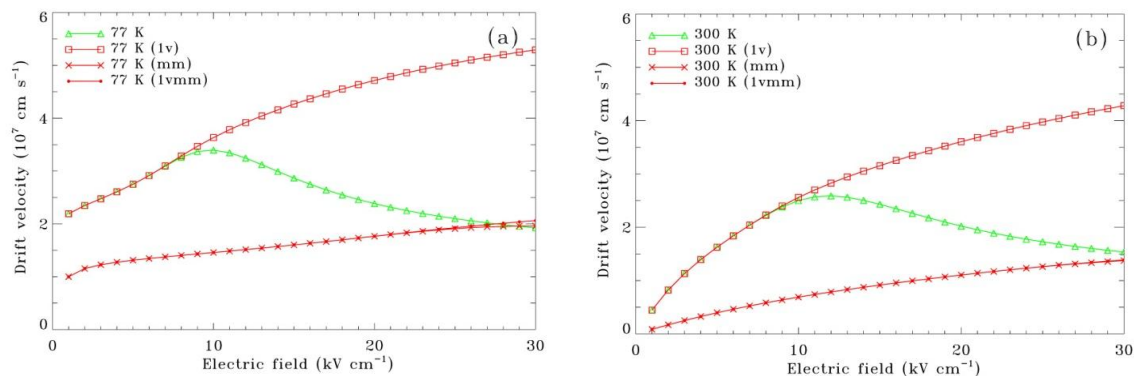


Figure 3. Electron drift velocity as a function of the applied electric field, for MC simulations of electron transport in InP with impurity density $n=10^{13} \text{ cm}^{-3}$, at lattice temperatures $T=77 \text{ K}$ (a) and 300 K (b), respectively. Results obtained from four different modelling of the band structure are compared: (i) three-valley model (green triangles), (ii) single-valley model (red squared, labelled “1v”), (iii) three-valley mean-mass model (asterisks, labelled “mm”), where the electron mass in all valleys is set equal to the mean value among the three effective masses in different valleys, and (iv) single-valley mean-mass model (dots, labelled “1vmm”), with the same effective mass as above.

Phase 3: What are the effects due to a change on the impurity density?

To highlight the effect of the interactions between free electrons and ionized impurities, randomly distributed inside the crystal, the instructors stimulated the students to investigate the peculiar characteristic of the electron transport in InP at different values of the doping density. At both the temperatures, the effect of impurity scattering is relevant only in the low-field region, where a decrease of the mean drift velocity occurs. Since ionized impurities scattering appear to be relevant mainly at low fields and/or at low temperatures, the students concluded that the impurity scattering rate decreases when the electron energy increases, becoming negligible in the high-field region (Figure 4).

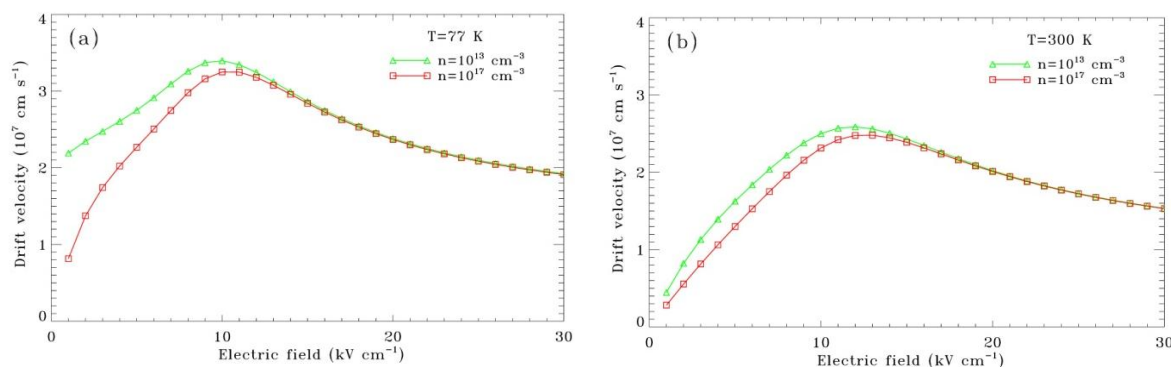


Figure 4. Averages of drift velocity as a function of the driving electric field, for MC simulations of electron transport in InP with impurity density $n=10^{13} \text{ cm}^{-3}$ (green triangles) and $n=10^{17} \text{ cm}^{-3}$ (red squared), at lattice temperatures $T=77 \text{ K}$ (a) and 300 K (b), respectively.

DISCUSSION AND CONCLUSIONS

Table 1. Students’ reasoned questions, planned simulations and concepts reinforced by the analysis of the outcomes from numerical experiments.

Inquiry sequence	Reasoned student questions	Planned simulations	Concepts acquired
Phase I	1) Which physical quantities affect the electron velocity-field characteristic? 2) How the electron energy changes at different values of the driving electric field? 3) What really happen to the electron ensemble at electric fields higher than the Gunn field?	Study of drift velocity, energy and occupation number of electrons in InP bulk for lattice temperature $T=77$ and 300 K and a driving electric field ranging between 1 and 30 kV cm^{-1} .	Gunn Effect; Role of intervalley transition; Dependence of phonon scattering probability on the temperature.
Phase II	How can we be definitely sure that the observed maximum in the velocity - field characteristic can be ascribed to intervalley transitions?	Study of electron dynamics, forcing all electrons to remain in the Γ -valley, independently of their energy and changing the value of the effective mass.	Effective mass as a measure of the inertial response of the system.
Phase III	What are the effects due to a change on the impurity density?	Study of electron dynamics at different values of the doping density.	Dependence of intravalley transition probabilities on the energy; Screened Coulomb interaction.

The active participation of the two instructors to the student debate on the physics governing the observed phenomena, elicited students' reasoning and activated a proficient scientific inquiry. In Table I we report the list of the students' reasoned questions among the three phases, effective in overcoming the standstills, together with the planned simulations and the conceptual knowledge reinforced by the analysis of the outcomes from their numerical experiments.

The relation between our teaching intervention and the student cognitive and affective development was investigated by methods of discourse analysis. The results coming from the analysis of student Speech Events (SE) are reported in Table 2. By following the work published by Donath and co-authors (2005), we have focused our attention to the following four SE: (i) Diagnosing, (ii) Critique, (iii) Explanation of research and (iiii) Awareness of knowledge gained. We have measured the percentage of students showing specific SEs during the simulated experiments on semiconductors, both during the initial phase of traditional guided inquiry and the three subsequent phases of elicited inquiry. In particular, this means that a percentage of 100% corresponds to the total number of students involved in our learning path. On average, we recorded a 35% of increase in the number of students' showing cognitive events, with respect to a traditional guided inquiry, related to diagnosing problems, critiquing experiments, explanation of research and awareness of knowledge gained.

Table 2. Percentage of students showing specific speech events (SE) during the simulated experiments on semiconductors, comparing the results coming from the application of a traditional guided-inquiry method vs. an elicited-inquiry strategy of instruction.

Speech Events (SE) (Donath et al. 2005)	Percentage of students showing SE during the simulated experiments on semiconductors	
	Traditional guided Inquiry	Elicited Inquiry
Diagnosing	30%	60%
Critique	40%	70%
Explanation of research	40%	80%
Awareness of knowledge gained	20%	60%

In the following, some quotes from students' speech events are reported for any one of the four SE typology:

- Diagnosing: "To address the role of scattering events, we could change the temperature in the simulations";
- Critique: "This finding cannot be real, I expect to see a drop in the carrier velocity ...", "We have to repeat the simulation: the energy saturates ..."
- Explanation of research: "Yes! It's the effective mass that drives the inertial response of the semiconductor system."; "Ok: electron scattering with ionized impurities is effective only at low temperatures..."
- Awareness of knowledge gained: "Now I have finally understood the role of intervalley transitions!"; "Yes, I got it: the effective mass determines the electron dynamics!"

This inquiry-based learning experience also allowed us to quantitatively address the student affective development and motivation to learn. This goal has been achieved by administering to our student a questionnaire based on the Intrinsic Motivation Inventory (McAuley et al.,

1989; McAuley et al., 1991; Vos et al., 2011), with specific items adapted to our study. In particular, we asked them to answer by trying to distinguish the feelings related to the traditional guided-inquiry approach from those related to the elicited-inquiry strategy of instruction. In order to quantify the student satisfaction we used a five-point Likert scale with the following meaning: 1-“Not at all”, 2-“Not really”, 3-“Undecided”, 4-“Somewhat”, 5-“Very much”. Here, in Table 3 we report the mean student outcomes to only four questions of our Intrinsic Motivation questionnaire; the first two are related to the interest-enjoyment dimension, the last two to the perceived competence dimension.

Table 3. Mean student outcomes on a five-point Likert scale to four questions of our Intrinsic Motivation questionnaire related to the interest-enjoyment and to the perceived competence dimension.

Questions (interest-enjoyment dimension; perceived competence dimension)	Mean student outcomes on a five-point Likert scale	
	Traditional guided Inquiry	Elicited Inquiry
1) I enjoyed this learning experience.	2.9	4.5
2) I am satisfied with my performance at this experience	2.1	4.4
3) After this learning experience, I feel pretty competent.	1.8	3.9
4) I'm pretty skilled on Semiconductor transport	1.8	3.6

The statistical analysis of the students' answers to the motivation/satisfaction questionnaire has shown a greater student appreciation up to 55% of the elicited inquiry environment with respect to the guided one. This confirms the awareness achieved by the students about the benefits that a specific activation of the inquiry process has had on stimulating their active role into knowledge construction.

Our findings clearly show a greater student participation, motivation and satisfaction to learn in an elicited inquiry based learning environment with respect to a traditional guided one. We found that teacher's role on providing suitable scaffolding is fundamental. Inquiry-based learning environments with lower teacher guidance may stimulate higher reasoning skills, but sometimes may produce negative feelings due, for example, to run into mistakes or achieve unexpected results (especially in not real-life problems). In our case the active participation of instructors, acting as student peers, was effective to stimulate students' reasoning and activate their scientific inquiry in terms of useful discussions and scientifically relevant questions. Each phase of the experienced learning path started from a reasoned question and included a set of simulative experiments whose results were explicative at some level of understanding and, at the same time, boosted the learners' thinking with further questions to be addressed by a deeper scientific inquiry.

In summary, our results show that the process of scientific inquiry in students facing unexpected findings in the study (even following a guided-inquiry based approach) of semiconductor physics (as in theoretical topics not directly observable in lab) may need a specific activation of the questioning process, supporting a valuable reasoned exploration.

The integration of a lecture-based method of instruction on semiconductor science with MC simulations embedded within a properly stimulated-inquiry teaching strategy, could represent a valid alternative to traditional guided inquiry learning paths, constituting an efficient

approach to effectively engage students into an active learning and producing an enhancement of the students' abilities in terms of diagnosing problems, critiquing experiments, constructing models and planning alternative investigations, which are all high-order reasoning skills required for future scientists or engineers.

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(PROSPECTIVE) BIOLOGY TEACHER'S SUBJECTIVE PERCEPTIONS ABOUT SELF-DIRECTED LEARNING

Christiane Hüfner¹ and Matthias Wilde¹

¹ Bielefeld University, Germany

Abstract: Individual concepts about learning and teaching have a significant impact on how teachers conceptualize and behave in class (Dubberke, Kunter, McElvany, Brunner, & Baumert; 2008; Helmke, 2009). These concepts and beliefs about learning and teaching can be seen as part of pedagogical content knowledge (Shulman, 1986; 1987) and as part of teachers' beliefs (Calderhead, 1996). The "developed theories of teaching" (Fox, 1983) describe the teacher as supporting the learners with their experience and expertise. In this case, learners become active participants in their own learning processes. An active learner and a supporting teacher are factors in self-directed learning (SDL; synonym to self-regulated, self-determined) (Faulstich-Wieland, 1997). This social constructivist concept of learning allows the science education researcher to search for the best learning procedure to implement in science classes. One such finding involves the use of biological phenomena to facilitate conceptual change (Duit & Treagust, 2003), and has been found to improve the student self-regulation. Other tools have been developed in science education to support SDL, and are discussed in detail in Schraw, Crippen, and Hartley (2006). The aim of the present study is to explore the nature of (prospective) biology teachers' understanding of SDL. Our approach involved using a semi-structured, guided interview to shed light on the complexity of teachers' knowledge about SDL, as used by Flick (2011). We then used Qualitative content analysis (Mayring, 2010) as a tool for discovering different subjective (i.e. non-scientific) categories about SDL from interview material. The results indicate vague and contrary subjective perceptions about SDL in general, and explicit subjective perceptions about specific elements of SDL, for instance the cognitive strategy 'elaboration'.

Keywords: self-directed learning, pedagogical-content-knowledge, biology class, teacher education, subjective perception

HIGH DIVERSITY OF SDL

The "cognitive revolution" (Kiper & Mischke, 2008) provided the impetus to perceive learning as a process, actively influenced by the learner as well as by internal and external factors (Schiefele & Pekrun, 1996; Schmitz & Schmidt, 2007). To conceptualize this learning process, different models and definitions emerged. In the literature, more than six different models can be found, divided into different types, for example layer and process models. In addition, the scientific community currently juggles more than five different definitions for SDL (Boekaerts, 1999; Knowles, 1980; Niegemann & Hofer, 1997; Schiefele & Pekrun, 1996; Weinert, 1982; Zimmerman, 2013). Weinert (1982) has expressed extensive criticism of SDL and its application in the German educational system. The author argues that SDL is

1. not a precisely defined scientific term,
2. not a consistently used label
3. is employed in everyday language
4. is an ambiguous, shimmering and ideological keyword.

That said SDL is also an important construct in American research on education. As such, Reischmann (1997) defined four different trends for SDL, while also offering criticism:

“Self-directed Learning has in English-speaking discussions the character of a religious maxim: in the main ‘self-directed’ - then you are in the right place in the adult education.” (Reischmann, 1997, S. 125)

Despite the great diversity in instantiations of SDL, the similarities can be listed as: 1. the center of SDL is the internal learning process, 2. the student is an active participant (makes decisions), 3. elements of cognition, metacognition and management of resources are present and 4. SDL depends on motivation and volition (Knowles, 1980; Weinert, 1982; Schiefele & Pekrun, 1996; Zimmerman 2013). This study focuses on SDL in pre-university teaching. As such, external control of the learning process is emphasized, per Schiefele’s and Pekrun’s (1996) definition.

“SDL is a way of learning, in which a person - **depending on his or her motivation** - decides to control the learning process in a self-determined way by employing **one or more control measures** (cognitive, meta-cognitive, volitional, behavioral) and to **monitor the ongoing learning process.**” (Schiefele & Pekrun, 1996, S. 258)

According to Schiefele and Pekrun (1996), SDL depends on various elements. Cognitive, metacognitive, volitional, motivational, and behavioral strategies are the most important (see Figure 1).

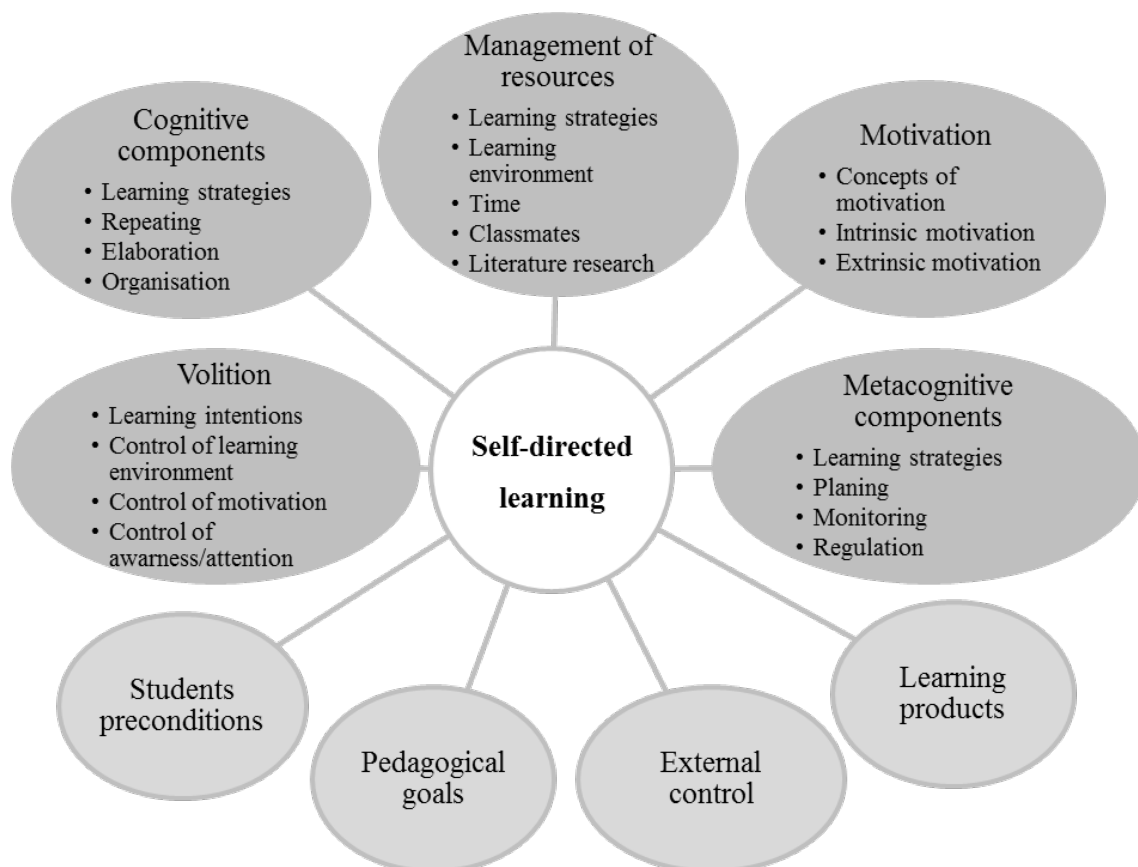


Figure 1. Components of SDL according to Schiefele and Pekrun (1996).

Furthermore, Schiefele’s and Pekrun’s (1996) model takes external regulation, which is essential to teaching, into account. Internal learning control, as described by Schmitz and Schmidt (2007) and Zimmerman (2013), represents the learning process in the learner. In the following, the importance of SDL will be elaborated. While gaining work experience, teachers develop individual subjective concepts. These often differ from scientific theories taught at universities (Helmke, 2009). To define “subjective concepts” as a scientific term,

three perspectives are important. First, according to Dann (1994), they can be identified as subjective theories. Several studies have shown that these theories are relevant for teaching biology (Wahl, 2000). Second, “subjective concepts” about learning and teaching can be seen as a part of professional knowledge (Grossman, 1990; Shulman, 1986, 1987). Third, according to Calderhead (1996), these concepts can be seen as a component of teachers’ beliefs. The three terms are combined, according to Hartinger, Kleichmann, and Hawelka (2006) and Magnusson, Krajcik, and Borko (1999) as *subjective perceptions* about SDL. These subjective perceptions are relatively constant cognitive structures and resistant to change (Pajares, 1992). One of the main functions of subjective perceptions for teachers is their influence on teaching (Diedrich, Thußbas, & Klieme, 2002; Hartinger et al., 2006; Peterson, Fennema, Carpenter, & Loef, 1989).

Our research question is thus:

How do (prospective) biology teachers subjectively perceive SDL?

To answer this question two hypotheses are established:

1. In general, there is a common understanding about SDL.
2. In particular, there are misconceptions about specific aspects of SDL.

METHOD

The subjective perceptions of 12 biology students and 17 biology teachers were collected using a semi-structured, guided interview (Flick, 2011). The goal was to uncover teachers’ complex knowledge about SDL. This method can be described as investigative and informational in accordance with Lamnek (2005). To optimize the interview process, four pretest interviews took place and led to the evaluation and improvement of the interview manual. Four interviewers were involved in the process of evaluation and interviewing. The interview consisted of eleven open ended questions, and was divided into two sections. At first, the interviewee was encouraged to discuss his own thoughts on teaching biology, especially concerning SDL. The interview began with questions intended to gain insights into teachers’ implicit knowledge about SDL. The interviewees were encouraged to talk about their individual experiences and ideas about SDL. For example, as shown by the following statements, we asked for situations in which SDL took place. But analyzing their statements the focus was placed on what the interviewee understood or meant by SDL:

In contrast to the first section, the second phase created a connection between the subjective and the theoretical concepts of SDL as described in Schiefele and Pekrun (1996), Schmitz and Schmidt (2007), and Zimmerman (2013). The definition of SDL was paraphrased, read out by the interviewer and read along by the interviewee. The interviewees were instructed to talk about SDL after being exposed to a theoretical formalization of SDL. These exposures led the interviewees to re-think their concepts or perceptions of SDL. Their narratives became closer to the theoretical construct of SDL. A typical example of a question in this section was:

“How would you enable your students to learn like that (SDL) in your biology class?”

Subsequent qualitative content analysis (Kuckartz, 2014; Mayring, 2010; Schilling, 2006) was used to analyze the material to ensure form relations between theoretical and practical concepts of SDL (deductive), and to develop categories from the interview material (inductive). Schilling (2006) in particular, introduced the process of qualitative analysis and created a spiral model of content analysis, which is adaptable to other research questions and different types of material. The analysis process was divided into eight steps (Mayring, 2010; Schilling, 2006), as shown in Figure 2.

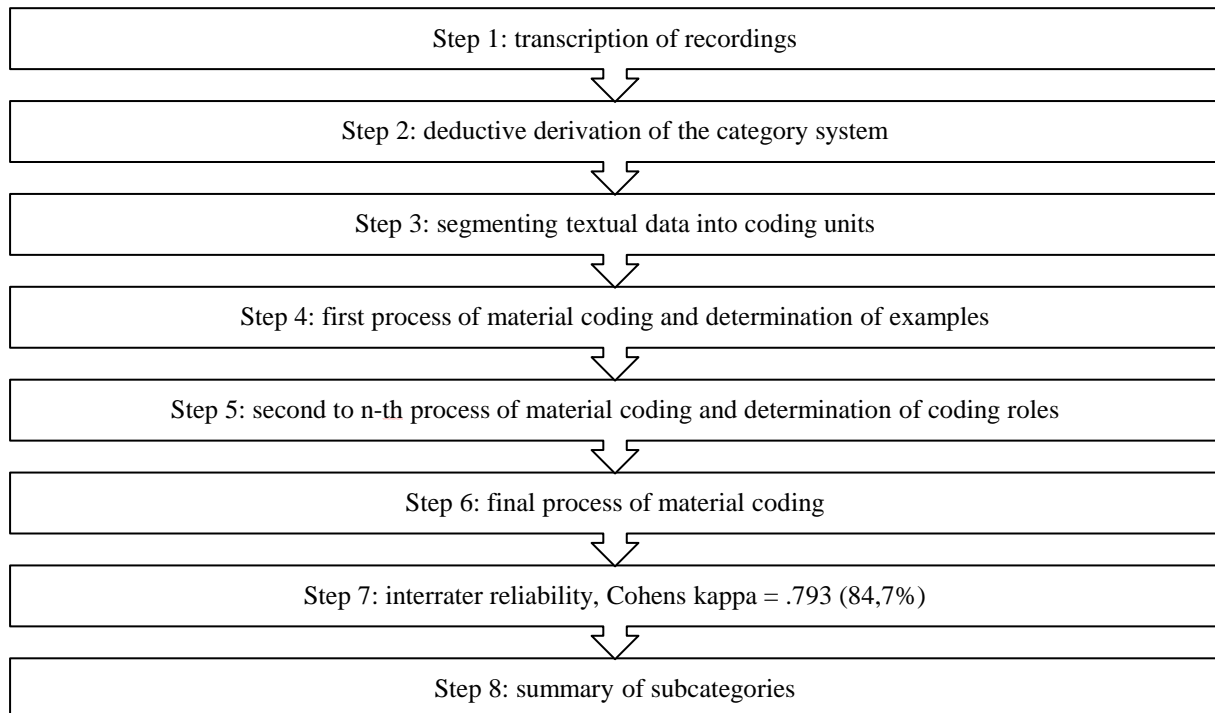


Figure 2. The eight *steps of content analysis according to Mayring (2010) and Schilling (2006)*.

Step two involved the ‘deductive derivation of the category system’. This system is based on an integrative framework model of SDL (Schiefele & Pekrun, 1996), reinforced and differentiated by the current literature (see Table 1). To link SDL with biology lessons, the main category ‘external control’ was expanded to include factors specific to biology didactics theories and methods, and professional operations in biology, i.e. experiments, use of a microscope (Baisch, 2012). To investigate the first hypothesis, coding units for the category ‘SDL in general’ were used only with the first section of the interview. The second hypothesis involved the main categories ‘SDL in general’ and ‘learning strategies’.

Table 1

Deductive category system of SDL

Main-Categories	Subcategories (examples)
Self-directed learning in general	<ul style="list-style-type: none"> • Description of SDL in biology lessons • Description of non-self-directed learning • Differences between SDL in biology and in other subjects
Learning strategies	<ul style="list-style-type: none"> • Cognitive learning strategies (elaboration, organization, repeating) • Metacognition • Learning strategies of management of resources

Volition	<ul style="list-style-type: none"> • Selective control of awareness/attention • Control of learning environment • Control of motivation • Control of emotion
Motivation	<ul style="list-style-type: none"> • Concepts of motivation • Concepts of motivation of achievement
External control of learning process	<ul style="list-style-type: none"> • media • types of schools • examinations • Learning environment • Teaching and instructional methods
Characteristics of learning products	<ul style="list-style-type: none"> • coherence • intensity • differentiation
Students preconditions	<ul style="list-style-type: none"> • experience • age
Pedagogical-educational goals	<ul style="list-style-type: none"> • responsibility of learning process

RESULTS

In general, four points can be made about the interview data: 1. the topics and contents of the assumed categories were all mentioned by students and teachers. 2. the main category 'SDL in general' disclosed the ambiguity, contrasts, and conflicts concerning SDL. 3. 'learning strategies in general' revealed differences from the theoretical framework, and 4. the subcategories corresponded to the theoretical framework (cognitive, metacognitive strategies, strategies of management of resources, motivation).

To investigate the first hypothesis, we analyzed the coding units for the main category 'SDL in general'. Summarizing these statements resulted in a few main points, which revealed the diversity and contradictions across conceptions of SDL (see Table 2).

Table 2

Main points of the main category 'SDL in general'

Main point	Example
SDL could be seen as something special, different or alternative. SDL is usually not part of ordinary biology classes.	<p>“What could also be possible, which I would imagine could work better, would be in the expected area. That one could open opportunities which are explicitly there, and that there are other aspects to be considered, and other fields to be edited. In this situation, you would also have time to proceed more independently.”</p> <p>“So 30 % - 40 %, I believe it would be something like that. Somewhere in that area.”</p>
SDL is imposed by educational politics.	<p>“Also, the whole thing is likely an attempt to improve the educational landscape. But, keep in mind, only an attempt.”</p>
SDL means students' learning without the teacher or with the teacher.	<p>“So, what I mean is, is self-directed learning always happening, even if I'm not present, or when does it happen, really? “</p> <p>“SDL means that it begins inside and works itself</p>

	out. It moves between guidance and independence.”
SDL must take place consciously or not and must be taught or not.	“I don't really think that's a big issue. Over time, every student will discover how he learns best. Having a new project where you learn how to learn, I found that extremely boring as a student, and I would hate to do that to my students now.” “So in my experience, just take things a step at a time and it will work out.”
SDL means method usage in biology classes or the creation of content.	“This is definitely where the big conflict lies, when we talk about self-directed learning. But it's a conflict between quality of content and becoming competent that stands in the way.”

As Table 2 shows, teachers' understanding of 'SDL in general' does not correspond with the theoretical framework, and differs considerably across interviewees. We investigated the second hypothesis by looking at the modification from diversity of SDL in general to specifications in the sub elements. For example, following a stairway from the main category 'learning strategies' will lead to the specific subcategory 'elaboration' (see Figure 3).

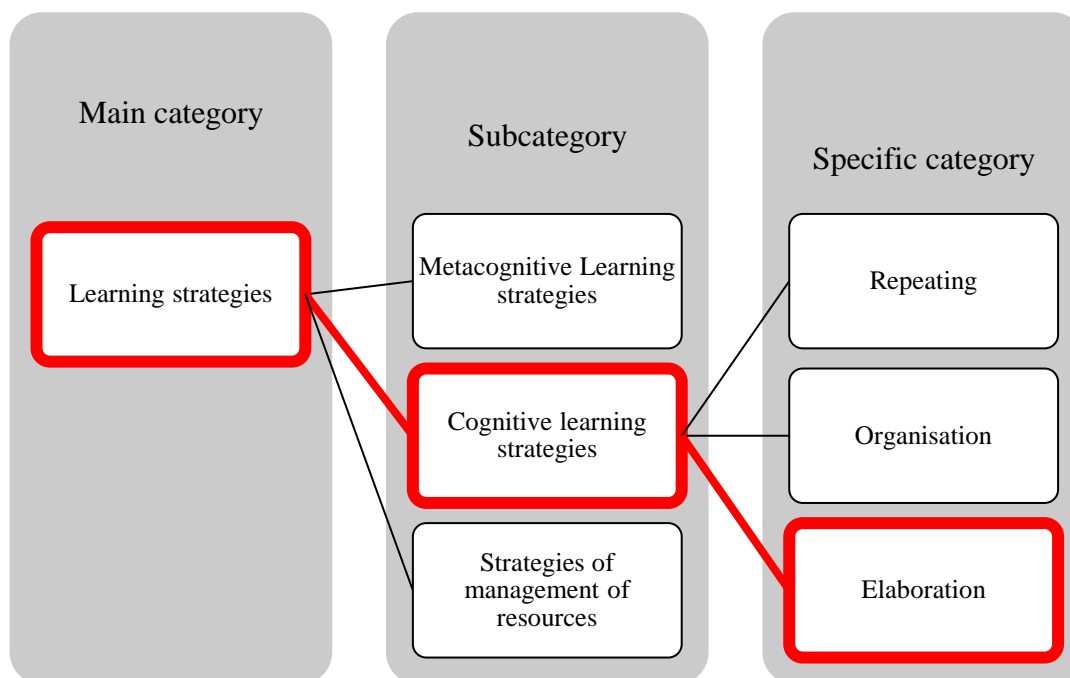


Figure 3. Stairway from diversity to specification.

Step one 'learning strategies' revealed unexpected deviations from the theoretical framework 'SDL in general'. An essential argument of the interviewees was that learning strategies must be taught until they are learned, as illustrated by the following statement:

“It's not over when you tell the student how to do it, but it needs to be exercised in a lengthy, difficult process. Until they work through this skill, and they finally develop it“.

Even though the learning strategies should be taught, some of the interviewees were unaware of specific learning strategies, as shown here:

“But having said that, I am also a little overwhelmed, particularly with learning strategies“.

Furthermore, learning strategies were regarded as competences.

“There are already an incredible amount of skills coming together. But exactly that is the point, not always just strictly reading the instructions on this or that page in the text, exercises 1 through 3. It's rather more sophisticated, the way abilities, skills come together“.

The second step, *'cognitive learning strategies'* revealed only a few differences from the theoretical framework. The main points are shown in Table 3.

Table 3

Main points in the subcategory 'cognitive learning strategies'

Main point	Example
Access to knowledge	“The access to knowledge, as they now see the opportunities to acquire knowledge, such as credible Media, now they see it first as a report on the Internet or they first read it in a free contribution to Wikipedia, they are taking the textbook into their own hands.”
Involve openly arranged biology classes	“When we speak here about different measures of control, I also understand it to mean my own learning pace and the ins and outs of how I handle things. And that can only happen when I have learning opportunities available that open up different approaches.”
Associate with factual knowledge and analyzing texts	“They must have reading skills, that's so important. If you can't read the tasks given, you have a big problem. Reading skills are essential.” “A concrete example? Okay so, for example, as it is now, when they acquire professional skill, they also need to have professional knowledge. And there are different ways that you can achieve professional skill and knowledge.”
Conscious use of cognitive learning strategies inhibits processing the actual task (examine)	“Hmm. And if they are sitting at the Biology Final Exam, well equipped with their cognitive strategies for textual comprehension, then they are so wrapped up in processing the material that they have no time to learn, or to write, it really doesn't work, though it sounds nice and great, I really think it's too difficult.”

The lowest step *'elaboration'* corresponded to the theoretical framework and included the three dimensions shown in Table 4. The first dimension, 'Elaboration of knowledge', described cognitive learning strategies, which enabled the elaboration of knowledge in general. The second dimension, 'elaboration of questions and hypotheses', described learning techniques, which support the scientific process of acquiring knowledge. And third, the dimension 'ways of elaboration' described situations and tasks in which students must elaborate. The meanings of the dimensions are explained in Table 4.

Table 4

Dimensions of the specific category 'elaboration'

Dimension	Example
Elaboration of knowledge: Development of topics; reflection on new content; recognition of contexts/relationships; critical thinking	“Content-wise, in places where they deal with the conflict of something, well, when I think of the area of Environmentalism in the 8th grade, in the area of ecology, there I can ask critically. For example when we're talking about sustainability.”
Elaboration of questions and hypotheses: Development of superordinate questions; independent formulation and processing (experiments); finding solutions of research questions	“Or, if one should ever first think of a question himself that he wants to investigate, wondering, how can I now verify this through experimentation.”
Ways of elaboration Forming and representing of opinion; creative writing process; processes of discovery of scientific knowledge (observation); planning of experiments	“Naturally, it would be better if this whole method of questioning and observation in order to gain knowledge would be left completely in the person's own hands.”

DISCUSSION AND CONCLUSIONS

In general, there exists congruence between theoretical and individual conceptions of SDL. The discrepancies between theory and practice will most likely be found in the main categories.

The first hypothesis of this study was about SDL in general. The assumption was that the subjective perceptions of SDL in general were close to the theoretical framework. This hypothesis must be rejected. Teachers' understanding about 'SDL in general' does not correspond with the theoretical framework. It differs greatly between interviewees. In general, there is no common understanding about SDL. So, the arguments by Weinert (1982) are still valid.

The second hypothesis was about particular aspects of SDL. The assumption was that the subjective perceptions of these aspects differed greatly from the theoretical framework. This hypothesis must also be rejected. Teachers' understandings of particular aspects match with the theoretical elements of the definitions and models of SDL by Schiefele and Pekrun (1996), Zimmerman (2013) and other scientists. These aspects are cognitive and metacognitive learning strategies, motivation and time management. In particular, there rarely are any misconceptions about specific aspects of SDL.

Some conclusions will be briefly discussed in the following. The main category 'SDL in general' shows that general opinions are not clear. In contrast, the specific concepts, for example 'elaboration', are clearly theorized and close to the framework. If there is a closer look at the main category 'SDL in general', the main statements could be seen as individual beliefs about SDL. Opposed to the main category, the specific subcategories reveal theoretical knowledge about SDL. It seems appropriate to connect the beliefs about SDL in general with theoretical knowledge about specific elements of SDL. A first step to realize this conclusion has taken place in the second part of the interview. The interviewees who were talking about their experiences with SDL were confronted with the definition of SDL. They had a chance to re-think their thoughts, beliefs and knowledge about SDL. A confrontation with SDL during the period of studies could be seen as part of professionalization to become a teacher. The same applies to other aspects of PK, PCK, and CK. The main categories uncover aversion to educational politics and negative ideas about SDL. It is possible that the aversions prevent

positive beliefs about SDL and their successful implementation in everyday school life. Two potential inferences are: first, in order to realize educational decisions concerning implementing SDL in biology, classes must become more important than knowledge about SDL. Teachers and students already possess the latter. Second, preventing and removing concerns about SDL must become more relevant in the teachers' professional training.

Summing up, surely the most important issue is to change SDL from an ideal or a specialty learning concept to an everyday usable concept.

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PICTORIAL LITERACY: AN ESSENTIAL SKILL IN SCIENTIFIC AND ANALYTICAL PROBLEM SOLVING

Julia Kobbe¹, Jenna Koenen² and Stefan Rumann¹

¹ University of Duisburg-Essen

² Humboldt-Universität zu Berlin

Abstract: Modern science text books contain a broad variety of diagrams. In order to learn students need to adequately encode the presented information and process it in line with the particular requirements of a given task. Therefore, diagrams play an essential role for knowledge acquisition as well as for scientific and analytical problem solving in terms of everyday life problem solving. But students are rarely instructed in the handling of diagrams systematically. Hence, a systematic training regarding the handling of diagrams could lead to increased learning acquisition as well as increased problem solving abilities. Thus, the aim of this study is to design and evaluate a systematic short-term training on *pictorial literacy* (Weidenmann, 1994a) under school routine conditions. It is hypothesized that a training on pictorial literacy has an improving effect on 9th grade students' scientific problem solving abilities as well as their general analytical problem solving abilities in terms of everyday life problem solving.

At the moment there is only little known about which methods and contexts are best suited for fostering pictorial literacy. Therefore, using the same framework, two analogous trainings were designed. One is based on everyday life diagrams, the second one uses scientific equivalents.

Both trainings were evaluated in a quantitative pre-post-study-design with 9th grade middle school students. In addition a control group attended a time-equivalent lab course to ensure time on task. Data acquisition included items referring to pictorial literacy, analytical and scientific problem solving as well as control variables referring to the student's demographic data, cognitive and reading abilities.

First descriptive results show that students in the control treatment group did not improve their analytical problem solving skills, and even showed a slight decrease in scientific problem solving. Whereas students in both training groups improved their problem solving abilities.

Keywords: pictorial literacy, problem solving, training program

INTRODUCTION

Theoretical Background

Images and diagrams play an essential role in knowledge acquisition and scientific and analytical problem solving (e.g. Koerber, 2003; Lachmeyer, 2008; Weidenmann, 1994b). As Schnotz, Baadte, Müller and Rasch (2010, p. 25) note: "*textbooks for science education are full of schematic drawings that show essential spatial or topological structures of a scenario, which is further analyzed in terms of the thematically scientific concepts.*" In general, students are confronted with a broad variety of images and diagrams. Most of them are not trivial but "*can be complex repositories of meaning, and students benefit on instruction in how to unlock them*" (McTigue & Flowers, 2011, p. 578).

The ability to deal with diagrams adequately, to “read” and understand the pictorial codes in an appropriate way is defined by Weidenmann (1994a) as “pictorial literacy”. According to Weidenmann (1994a) pictorial literacy is highly underestimated in the educational system and a systematic approach regarding the handling of pictorial codes is usually not taught at all. He pinpoints, that processing instructional pictures and diagrams is a problem solving activity and routines acquired by natural perception cannot be used for the reconstruction of the full visual argument (Weidenmann, 1994b).

As McDermott, Rosenquist and van Zee (1987) showed, even among university level science students difficulties in comprehension and interpretation of graphs are prevalent. So far only little research has been conducted on actually teaching students how to comprehend diagrams more efficiently (Cromley et al., 2013) and how to encode the entailed information systematically. Cromley et al. (2013) examined a method called “Conventions of Diagrams” (COD) on a small sample of 10th grade biology students. Students in the COD-group got “diagram decoding tips” for eight conventions (e.g. captions and labels) used in original biology textbook diagrams. They showed a statistically significant larger growth in comprehension of literal and inferential biology diagrams compared to conventional instruction without systematic “diagram decoding tips”.

Problem Solving Competency: Problem solving competency is seen as a central objective within the educational programmes of many countries (OECD 2010) and was, therefore, assessed as an additional domain in PISA 2003 and PISA 2012. Frensch & Funke (1995) have pointed out, that many, often incongruous, definitions of problem solving and problem solving competence can be found. Since this study uses some of the original PISA analytical problem solving items, their definition of analytical problem solving competence is used. Analytical problem solving is defined as the “*individual’s capacity to use cognitive processes to confront and resolve real, cross-disciplinary situations where the solution path is not immediately obvious and where the literacy domains or curricular areas that might be applicable are not within a single domain of mathematics, science or reading.*” (OECD, 2004, p.156) Thus, analytical problem solving items confront students with paper-pencil-test-based problems which need to be solved similar to everyday life scenarios. Scientific problem solving is defined very similar, but here the problems refer only to science.

For many common problem solving tasks, both in school and everyday life, it is essential to pick the information needed for being able to solve the problem out of a given diagram (Frackmann & Tärre, 2009). An improved pictorial literacy should provide students with one of the essential prerequisites needed for the successful handling of this kind of task.

Due to the importance of diagram handling a broader and systematic approach regarding the training on pictorial literacy seems both requisite and promising.

Focus of the Study and Research Questions

Therefore, the aim of this study is to develop a systematic short-term training on pictorial literacy and its subsequent evaluation under school routine conditions. The training gives a systematic introduction into pictorial codes and conventions used in the most common (middle school relevant) diagram types. Additionally, the course contains general guidelines regarding the handling of manifold diagrams and images. These strategies are meant to support students, when faced with scientific and non-scientific images and diagrams, which cannot be strictly categorized or which include unfamiliar elements.

Using the same framework, two analogous trainings were designed. One is based on everyday life diagrams, the second one uses scientific equivalents, to control for potential subject matter effects. With help of a newly developed test on pictorial literacy the effectiveness of

the respective training programs is analyzed, both as a treatment control and for comparison between the training programs.

It is hypothesized a training on pictorial literacy has an improving effect on 9th grade students' scientific problem solving abilities as well as their analytical problem solving abilities, due to the required handling of diagrams in these tasks.

The effects of the short-term-training course in pictorial literacy on students' scientific and analytical problem solving abilities are presented in this paper.

DESIGN AND METHODS

Design of the Training Material

In order to identify the most important school relevant diagram types the first step was an exploratory analysis of middle school science textbooks. An additional exploratory analysis of PISA-Items was conducted to identify the respective pictorial codes. In accordance with these findings, two analogous trainings were designed to test potential effects of image and diagram topics on the transfer to the other domains. Despite the different topics of the respective examples, all image details were designed in a congruent way. One training (treatment I, see also study design section) uses science-specific examples while the second training (treatment II) uses everyday life equivalents.

The training courses are workbook-based training programs with classroom discussions and student exercises on all presented diagram examples and the respective features. Each workbook includes the following aspects:

- a) A systematic introduction into pictorial codes, conventions and general aspects of images and diagrams (e.g. captions, labels, spatial composition)
- b) General guidelines for image and diagram processing
- c) Spreadsheets and "mathematical" diagrams (spreadsheets, scatter and line diagrams, histograms)
- d) Arrows, colors, spatial composition and other details e.g. in cross-sections, experimental set-up images, maps
- e) A final complex problem solving exercise with images and experimental settings referring to aspects of all workbook chapters

The first two chapters, especially „general guidelines for image and diagram processing”, serve as golden thread throughout the training. The subsequent chapters take a more detailed look on discrete image types and the respective features. Each workbook chapter is accompanied by a detailed glossary and by student exercises.

Excerpts of the Training Material

A systematic introduction into pictorial codes, conventions and general aspects of images and diagrams:

The training starts by drawing the student's attention to the benefits and the challenges that come with the use of diagrams.

In the training including the science-specific examples the student workbooks begin with a *text* explaining how to fold a filter paper for a filtration. Every step is explained in detail. After a short discussion of the text, the students get a *diagram* showing the same steps and information (see figure 1). The benefits of this pictorial representation are discussed. Special attention is drawn to the numbering, the arrows and the dashed lines to make students aware of the fact that knowledge about the meaning of such image details is inevitable to understand the diagram.

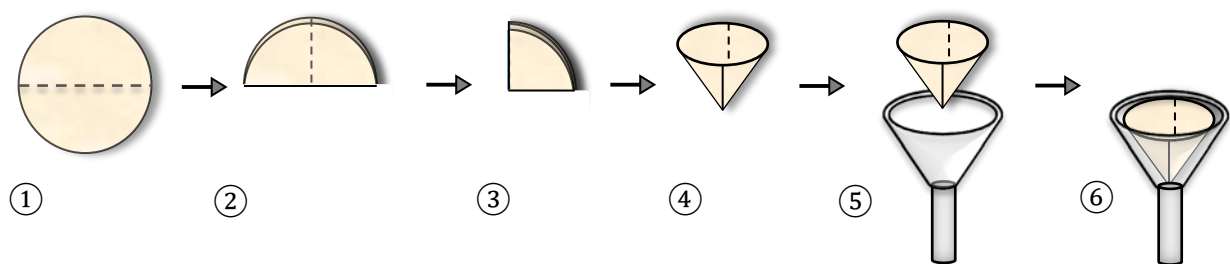


Figure 1: Excerpt of the training program student workbook (science-specific examples): folding a filter paper for filtration

Students taking part in the training using everyday life examples get the same introduction with a very similar text and diagram example. But instead of a guideline for folding a filter paper for a filtration, they get a construction guide to build a brick-based toy, similar to those of a well-known Danish toy brand.

After this introduction, students of both training groups get an example of a more complex image. They have to work on a map, to give them a systematic instruction into some general aspects of images and diagrams, like captions, labels, scale and legends. Students learn how to find and how to use these aspects in order to process the information included in the image adequately. Furthermore, function and meaning of symbols, colors, shading, continuous/dashed lines and spatial composition are discussed in detail.

As described above, students in both trainings work on similar maps, but the domain-specificity of the presented examples differs. Students studying with science-specific examples work on a map with biological content (see figure 2) and matching exercises, whereas the map included in the everyday life training refers to holiday planning.

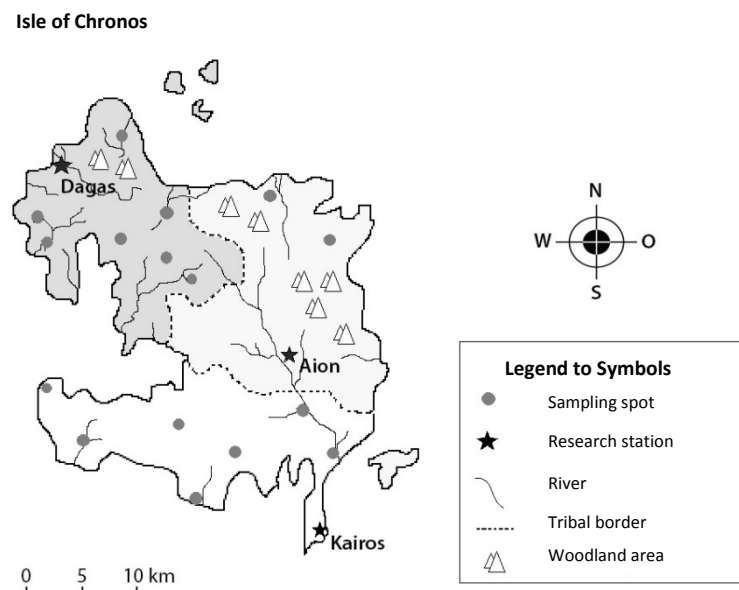


Figure 2: Excerpt of the training program student workbook (science-specific examples): introduction into some general aspects of images and diagrams

General Guidelines for Image and Diagram Processing:

Before discussing the most common school relevant diagram types, some general guidelines for image and diagram processing are given to the students. These guidelines are not presented here in detail, but a summarized excerpt and the main focus is shown in figure 3.

*In most cases students have to solve a certain problem or task. Students have to ask for the target of their task and the information needed. **One source** of information can be images and diagrams. So, in general, when processing these, students have to ask **which information can be drawn from the diagram** to solve the problem or task?*

Necessary steps for handling a diagram:

- I) **Getting an overview:** What is shown in the diagram? What is the context of the diagram? How many parts does the diagram have and what kind of diagram is presented?
- II) **Getting a closer look at the diagram details and their significance:** How to deal with captions, labels, legends, symbols, colors, shades, shapes, spatial composition, arrows and so on? What significance do they have and how are they connected towards each other?
- III) **Taking a step back and considering the whole diagram:** What is the significance of the whole diagram?
- IV) **Control of the drawn conclusions:** Is my perspective towards the diagram appropriate and the only appropriate perspective or do I have to consider further aspects?

Figure 3: Summarized excerpt of the “General Guidelines for Image and Diagram Processing

Study Design

A quantitative experimental study was conducted with 9th grade middle school students ($N = 315$). Twelve classes were randomly assigned to two training and one control group treatments (cf. table 1). Data acquisition was obtained by means of a pre- and a post-test. Both tests included 27 newly developed pictorial literacy items, 12 PISA analytical problem solving items and 16 PISA science items defined as scientific problem solving items.

Treatment I and II took place as six-hour training courses in pictorial literacy. The control group took a six-hour lab course to ensure time-on-task. The lab course demanded similar work with images and diagrams, but did not include an explicit training on pictorial literacy.

Table 1. Design of the study

Pre-test (135 min)	Treatment I:	Post-test (90 min)
<u>Dependent variables:</u> 27 Pictorial literacy items 12 Analytical problem solving items 16 Scientific problem solving items <u>Control variables:</u> Demographic information Cognitive abilities Reading ability Cognitive strategies Motivation Cognitive load	6 hours pictorial literacy training based on science-specific examples	<u>Dependent variables:</u> 27 Pictorial literacy items 12 Analytical problem solving items 16 Scientific problem solving items <u>Control variables:</u> Motivation Cognitive load
	Treatment II 6 hours pictorial literacy training based on everyday life examples	
	Control Treatment: 6 hours lab course	

RESULTS

Data acquisition of the study was finished in summer 2015 and the data analysis is still going on. Therefore, only first descriptive results are presented.

Analytical problem solving: At the time of the pre-test, students in the two training treatments and in the control group achieved a mean of 5.4 points (SD 3.0), with a range from 0-15 points (of 18 possible points). The range for the post-test was 0-17.

Table 2. Results for analytical problem solving

	PRE-test	POST-test
	<u>Analytical problem solving</u>	<u>Analytical problem solving</u>
	Mean values	Mean values
Treatment I (scientific examples)	5.4 points (SD 3.0)	7.0 (SD 3.9)
Treatment II (everyday life examples)	5.4 points (SD 3.0)	7.0 (SD 3.4)
Control treatment (lab course)	5.4 points (SD 3.0)	5.4 (SD 3.0)
All Groups	5.4 points (SD 3.0)	6.5 (SD 3.6)

From pre-test to post-test, students of training group I (science-specific examples) and students of training group II (everyday life examples) increase similar in their analytical problem solving skills, while there is no shift for students of the control treatment.

Scientific problem solving: At the time of the pre-test, students in the two training treatments and in the control group achieved a mean of 5.2 points (SD 2.9) with a range from 0-15 points (of 19 possible points). The range for the post-test was 0-16.

Table 3. Results for scientific problem solving

	PRE-test	POST-test
	<u>Scientific Problem Solving</u>	<u>Scientific Problem Solving</u>
	Mean values	Mean values
Treatment I (scientific examples)	5.2 points (SD 2.9)	6.0 (SD 3.7)
Treatment II (everyday life examples)	5.2 points (SD 2.9)	6.4 (SD 3.6)
Control treatment (lab course)	5.2 points (SD 2.9)	4.3 (SD 2.9)
All Groups	5.2 points (SD 2.9)	5.7 (SD 3.5)

From pre-test to post-test, students of training group I (science-specific examples) and students of training group II (everyday life examples) slightly increase in their scientific problem solving skills, while there is a slight decrease for students of the control treatment.

CONCLUSIONS AND PERSPECTIVE

First descriptive results show that students in the control treatment group did not improve their analytical problem solving skills as well as their scientific problem solving skills from pre- to post-test. The results of both treatment groups regarding problem solving abilities can be seen as an indication that students benefit from the training program on pictorial literacy. Further analysis will give a more detailed view on these findings.

The influence of the treatments on pictorial literacy itself still needs to be analyzed. This will provide more insides on the development of students' pictorial literacy for the trained components. Treatment I and II offer the same image detail information, but differ in the domain-specificity off the presented application examples. Effects of the different examples will be discussed in the future, with special emphasis on the increase in pictorial literacy as well as its transferability to other domains.

Summarized these first results indicate that it seems to be possible to design a short-term training on pictorial literacy that has an influence on problem solving abilities. Nevertheless, the influence of the treatments on pictorial literacy itself still needs to be analyzed and will provide a more detailed picture on these findings and the effectiveness of the training.

Contribution to Teaching and Learning

As described earlier pictorial literacy plays an essential role in knowledge acquisition. One aim is to support teachers in their task to foster students' skills in pictorial literacy by offering systematic teaching materials that can be used in a broad school subject context. As a medium-term goal, a general implementation of a systematic training on pictorial literacy in standard school instruction, as well as in teacher in-service training, should be discussed.

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TEACHER ACTIVITIES FOR STRUCTURING STUDENT KNOWLEDGE AFTER CHEMISTRY LABWORK

Rita Khanfour-Armalé¹

Jean François Le Maréchal²

¹Université de Cergy Pontoise (Institut d'éducation d'Antony, Espé de Versailles), LDAR, EA4434, Université Paris Diderot, Sorbonne Paris Cité, Paris, France.

²LC ENS de Lyon, UMR 5182

Abstract: The laboratory has been given a central role in science education. Laboratory activities have the potential to enhance constructive social relationships as well as positive attitudes and cognitive growth (Hofstein & Lunetta, 1982). But laboratory sessions cannot by themselves be in charge of the whole learning and cannot govern the overall learning process even if they have been carefully designed. In fact, knowledge is not presented in as well structured and formal manner as it was with a classical transmissive teaching. In this study we focused on understanding the moment (that we named debriefing) in teaching sequences when teachers structure the knowledge developed during labwork. To study debriefing, our theoretical framework was based on conversational analysis and knowledge analysis. Three kinds of debriefing were observed. The first kind took place as a teacher review of all the questions raised by the labwork and provide their answers during a class discussion based on ternary exchanges (question, answer, evaluation). Most of the teacher's questions were based on the assignments for the labwork or on the context of the students' observations. The teacher's evaluations appeared to be the interventions that introduced and structured knowledge. The second kind of debriefing involved a document provided by the teacher. This document summarized knowledge, either linking several units of labwork or one unit with other phases of teaching. During such a debriefing, the class discussion was still based on a ternary exchange. More knowledge was developed than during the first kind of debriefing. Last, the third kind of debriefing was based on a lecture that cannot be modelled as a ternary exchange. The structure of such a lecture could either follow the organization of the labwork or diverge from it. When it did not, the link with the labwork was limited to few experimental works that had been given as examples during the lecture.

Keywords: teacher's practices, postlab, interaction, ternary exchange, facets of knowledge

CONTEXT OF THE RESEARCH

Although several decades of research in chemical education have stressed on the importance of experimental activities in learning, there is still no widely accepted theory of instruction or carefully thought out manageable methods of implementation consistent with constructivist theory (Williams & Hmelo, 1998, p. 266). It has been recognized that laboratory activities have the potential to enhance constructive social relationships as well as positive attitudes and cognitive growth (Hofstein & Lunetta, 1982), but mismatches often occur between teachers' perceived goals for practical work and students' perceptions of such activities (Hodson, 1993, 2001; Wilkenson & Ward, 1997). Laboratory sessions cannot by themselves be in charge of the whole learning and cannot govern the overall learning process even if they have been carefully designed, because knowledge is not presented in as well structured and formal manner as it was with a classical transmissive teaching. For the last 15 years, our group has been involved in the design of teaching sequences (Buty et al., 2004) the goals of which are to make explicit the relations between objects that are manipulated, events that are observed, and models that are the goal of teaching. Our group was also integrating other metacognitive learning experiences, such as "predict-explain-observe" demonstrations (White & Gunstone,

1992). Laboratory work must incorporate the manipulation of ideas instead of simply that of materials and procedures. We hope that these will promote the learning of science. Although research data show that students seem to profit from such experimental sessions in so far as they allow students to relate the experimental field to theory and models (Tiberghien, 1994), teachers are not comfortable with laboratory work designed as such. Knowledge is actually involved during the laboratory sessions but, as Chang and Lederman (1994) and others (e.g. Wilkenson & Ward, 1997) have found, that students do not have clear ideas about the general or specific purposes for their work in science laboratory activities (Chang & Lederman, 1994). As a result, during laboratory activities, students involve the knowledge that is to be learned, but also incorrect knowledge (within observations and interpretations) without being aware of it. Teachers are somehow disoriented. Among the reasons of this disorientation, we have found, during interviews and group discussions:

- the large heterogeneity of the relation between students and the new knowledge after experimental activities,
- the fact that students have involved and start learning a new knowledge that is neither properly formulated nor structured, and
- the fact that there are little visible paper traces of the knowledge as the students' laboratory notebooks do not seem appropriate for further teaching/learning.

Teacher intervention is therefore necessary in order to point out the correct and the incorrect knowledge, to formulate and to structure it. As only a few teacher interventions occur during the laboratory sessions, a moment where the teacher can come back to the knowledge to be learned must be planned during the teaching sequence. A way to enter more deeply into the learning process is therefore to analyze a class discussion during this "come back". It might involve linguistic tools for structuring the discussion as well as didactic tools to specifically understand and compare the knowledge imbedded into the teacher-class interaction.

The aim of our research has been to provide a new insight into these moments occurring after profitable experimental activities. We are interested in understanding what the class organization can be after the labwork. We have given the name of "debriefings" to these moments. During a debriefing, the teacher takes back the responsibility of organizing the knowledge after having let his/her students be autonomous during the laboratory work. We consider that these moments are debriefings only if the teacher comes back to the concepts imbedded in the activity within the same context as the experimental situations. In most cases, the texts of activities that we found in the research literature and in the school textbooks are structured around questions that are submitted to learners. Although the class following the activity can be organized in different manners, and it will be discussed below

THEORETICAL BACKGROUND

We consider that knowledge in class can be reconstructed from examining the teacher-class interaction. This interaction has been analysed from two perspectives:

- a linguistic analysis based on ternary exchange (Lemke, 1990; Mehan, 1979) and
- a didactical one based on a division of knowledge into facets (Minstrell, 1992).

1. Linguistic analysis

In the linguistic analysis, when teachers go through the students' laboratory work with them in class, we consider a class discussion as a dialog between two interlocutors: one single privileged interlocutor and a collective interlocutor, i.e. the teacher and the class respectively, considered as one interlocutor. Such interactions should be seen as a "dialogue", and not a multilogue, because of the organization of the class makes it possible. The basic structure of the conversation in class can be viewed as terms of ternary exchanges or triadic dialogue (I.R.E.) (Lemke, 1990; Mehan, 1979).

In the ternary exchange:

- I is an initiation by one interlocutor;
- R is the answer by the other interlocutor and
- E an evaluation of the answer by the first interlocutor (Kerbat-Orrechioni, 1996).

Such a ternary exchange analysis has also been used in science education (Mortimer, 1998; Manzoni-de-Almeida et al., 2014) and it will be the base of our analysis. This sequence currently noted I-A-E has been observed in class discussions (Mortimer, 1998). Deviations from this basic ternary exchange are interesting to understand, as are the characteristic of the interactions – we have, for example, compared their lengths.

The teachers' behaviour can be either dialogic or authoritative (Scott & Mortimer, 2002) according to the way they consider the students' knowledge. Interactions are dialogic whenever teachers consider students' knowledge in the evaluation phase, or later in the new question. Otherwise, interactions are authoritative. We believe that a condition for learning comes from a continuity of the knowledge, especially between the student's answer and the teacher's evaluation. Looking for such continuity is, therefore, a promising analysis of the teachers' activity.

2. Didactical analysis.

In the didactical analysis, the division of knowledge from a facet perspective allows it to compare the knowledge involved in the interactions of different situations. Facets are units of knowledge that are reconstructed from utterances. For comparisons between different situations to be possible, this reconstruction has to respect the idea carried along by the utterance, and include a generalization of contextual words.

RESEARCH QUESTIONS

We agree with Polman's claim (1999) that to foster science learning through projects and inquiry, teachers must play a complex role. But which role?

The aim of this research is to

- study during postlab sessions, the teacher's interventions and
- better understand the way knowledge is at work during the postlab sessions

During the postlab that we named debriefing, teachers have the opportunity to point out the relevant knowledge that has been used during the laboratory session.

Once we are able to describe the debriefing, it will be possible to make a hypothesis on their improvements and measure their effects on learning. This study is limited to describe the debriefing. We will base our description on three elements:

1. where teachers get their ideas for questions to ask the class?
2. the interactions between the teacher and the students, and
3. the types of teacher evaluations.

We hypothesized that evaluations of the students' answers can be done from the teaching situation (i.e. from students' words or from students' knowledge about the situation) or from a modelling activity. In the latter case, the teacher can use the student's ideas (word or knowledge) either to return to the context of the task (contextualization), or to introduce ideas relative to the model (generalization).

Our research questions are:

- what are the possible class organisations to debrief laboratory activities and
- how is it possible to characterize them in terms of their linguistic structure and scientific content?

METHODOLOGY

Our main source of data is a corpus of 35 class videos recorded with the camera focused on the teacher. Five teachers were observed as they were debriefing experimental activities at the upper secondary level in chemistry classes. There was 30 to 35 students per class. These activities were drawn from a pool of nine; most of them had been designed during meetings between these teachers and our research group.

The conversations between teachers and their class were transcribed. In one hand, the transcriptions were split into ternary exchanges. The initiative interventions of ternary exchange were compared to the questions of the text of the laboratory work. In the other hand, facets of knowledge were extracted from the teachers' and students' utterances where sensitive concepts were involved. A concept is said to be sensitive when the teacher has a learning objective regarding this concept.

RESULTS

Our analyses led us to consider three kinds of debriefings:

- feedback debriefing,
- summary debriefing and
- lecture debriefing.

For all of them, the teachers were back in charge of the knowledge to be taught. They used the same sensitive concepts as those the students had used during the laboratory work, and in the same context. All the debriefings are at a class level and occurs after a part or a completed laboratory work. We will present the debriefing in terms of teacher's practices and not in terms of students' understanding after the different approaches.

1. Feedback debriefing

Feedback debriefing is by far the most observed practice (30/35). During such a debriefing, the teacher has in his/her hands the text that the students had worked with. S/he reviews most of the items in the same order. The class discussion is most often (81%) structured as ternary exchanges, with the teacher's questions serving as initiators for interaction.

These questions have been categorized (see Fig. 1) as text questions if they belong to the text of the laboratory task (22.7%, N = 366), and non-text questions (77.3%). For the latter, 44.8% deal with the context of the experiment, 5.6% are meta-questions (reflections about the knowledge), 5.4% are based on relations between different text questions and 3.9% are given as simplifications of a text question. This categorisation left over 17.6% of uncategorised questions that are mainly continuity interventions such as: "and then?" or "what else?" to incite the student to keep on talking and to allow further insight into student understanding.

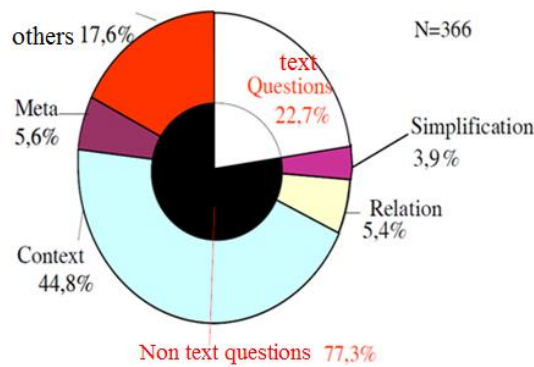


Fig. 1: The teacher's questions during the feedbacks debriefing.

Student interventions were categorised in terms of I (initiation)-A (Answer)-E (Evaluation). Most of them were A (97% see the Fig. 2 below), a few were I. All initiations were questions. The former category often dealt with observations or interpretations. In the interventions we observe a small answer to the questions of teacher like yes or no. The students describe also in their answer (5%) the manipulation of object used in the labwork. Just 9 applications of formulas, 10 memorisations and 6 previsions make during the labwork.

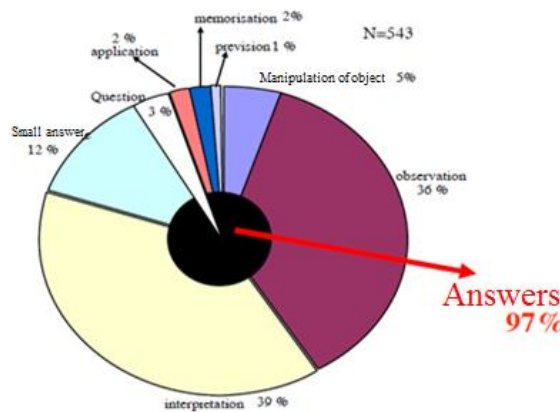


Fig. 2: The student's interventions during the feedbacks debriefing.

After the teacher's initiations and the students' answers, the teacher's evaluations were categorized. The most frequent E-interventions were formulations. A formulation could be a teacher's repetition or reformulation of the student's answer (57%, N = 791, there could also be more than one category of evaluation per ternary exchange). The teacher could also deal with the knowledge imbedded in the student's answer (treatment of knowledge 26%), contextualise it (11 %) or generalise it (6 %). Although generalisation and contextualisation are of prime importance in science teaching, as it happened, the teachers spend little time with these activities. Moreover, they spend little time in asking questions that could be cognitively motivating (relation, meta), or helpful (simplification).

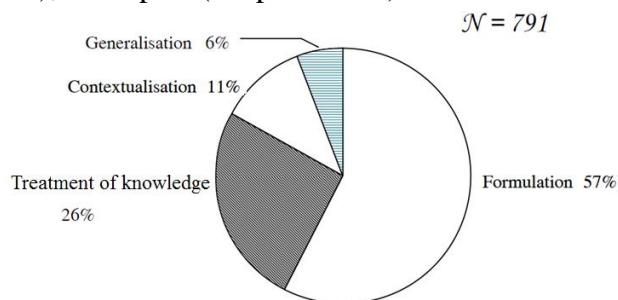


Fig.3: The teacher's evaluations during the feedbacks debriefing.

These data are in agreement with the fact that students often get bored during such debriefings; when we recorded the videos, students did not pay much attention to the teacher unless they were requested and produced a background noise. In addition, teachers feel uncomfortable with feedback debriefing. When interviewed about the reasons for doing it, they said that they felt obliged to come back to the activity they had proposed to the class and that this format is easy to work with. Two other kinds of debriefing are presented next.

2. Summary debriefing

Summary debriefings are organised around a document that the teacher gives to pupils, with a summary of the knowledge to be learned. The facets of knowledge were found to be the same in the summary and in the corresponding experimental activities. Only 3 summary debriefings were found out of 35, but when asked about their practices, teachers sent us 4 other summaries that had been used in debriefing conditions. Such a debriefing is therefore not as rare as the analysis of our corpus might suggest.

In the summary (Fig. 4), experiments may be compared (thin layer chromatography / column chromatography).

A_ Séparation d'espèces chimiques : la chromatographie

La chromatographie est une technique de séparation d'espèces chimiques, on peut la réaliser sur colonne (cf TP du jus de tomate) ou sur couche mince (TP CCM des colorants alimentaires).

Dans tous les cas, il faut un support ou phase fixe et un solvant ou phase mobile.

TP	phase fixe	phase mobile	migration par
jus de tomate			
colorants alimentaires			

Le principe de la chromatographie repose sur la solubilité des espèces chimiques dans les solvants : **plus une espèce chimique est soluble, plus elle sera emportée par le solvant.**

Fig.4: Comparison of the thin layer and the column Chromatography in the summary document.

Teachers may also hinge sensitive concepts introduced in different lessons (Lewis representation / Cram representation). One of these courses may be the following in the teaching sequence. One of the aims of the summary is to provide the students with a written record, whereas during feedback debriefing, most, if not all, courses are oral. In the summary, the language is more formal and complex than during the oral discourse of the feedback debriefing. The knowledge is presented in another semiotic register. We found that the summary was commented in relation to the experiment done in class, or just assigned as homework.

3. Lecture debriefing

In lecture debriefings, teachers develop a structured presentation of the knowledge that includes the sensitive concepts of the laboratory work and present it to the class. We observed only two lecture debriefings.

In the first one, the organisation of the knowledge was the same as the text of the laboratory work activity (Fig.5 in black color), with the addition of a few extra examples and topics (Fig. 5 in blue color). Just 2 modifications was done (Fig. 5 in red color).

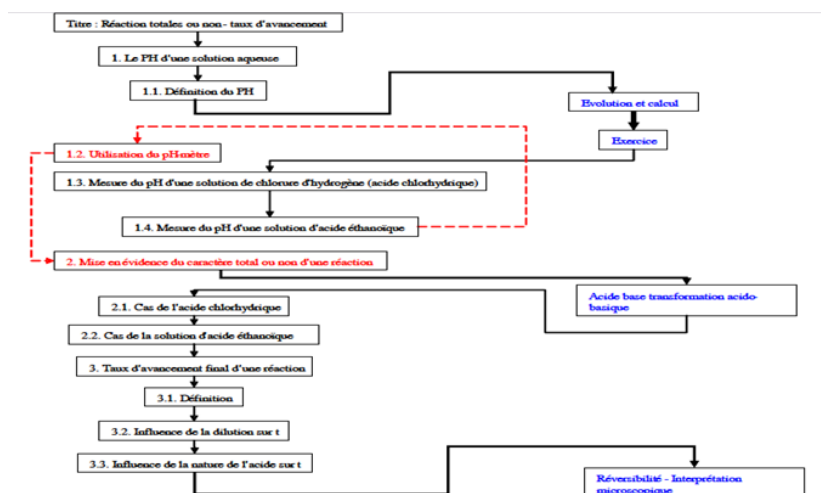


Fig 5: The organization of the knowledge in the first lecture debriefing.

In the second one, the organisation of the knowledge was different (Fig. 6). Much more facets were used in these debriefings than in their corresponding laboratory sessions (66 vs. 8 in one case and 54 vs. 10 in the other one). The link between the laboratory work and the debriefing came from several examples (Fig. 6 in blue color) of the former that were introduced in the latter (Fig. 6 in black color).

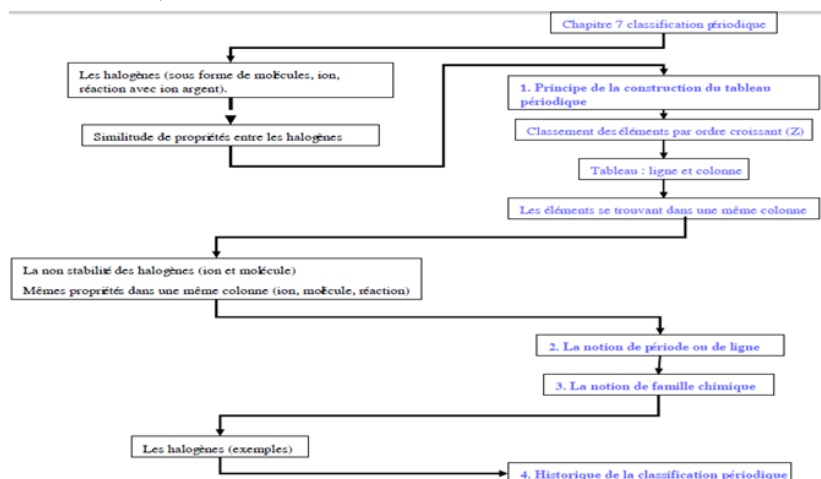


Fig 6: The organization of the knowledge in the second lecture debriefing.

Unlike the feedback debriefings, as it happened, students took the initiative in ternary exchanges and asked questions (25 in one case and 45 in the other one). These students' attitudes show their motivation in and interests for lecture debriefings.

The linguistic structure of the lecture debriefings was different from the one observed for other types of debriefing. Half of the ternary exchanges were interrupted by a long comment by the teacher. This comment was neither an evaluation of the previous exchange, nor an initiative toward the following exchange. We called this comment "counter-exchange". The density of facets was higher during the counter exchange than at any other moment of the debriefings (50% of the facets attributed to the teacher during the debriefing).

CONCLUSION AND TEACHING IMPLICATIONS

Our research has been able to provide an understanding of the way teachers come back to an experimental activity. Such an understanding may help to improve novice teachers' practices as our feeling is that they will spontaneously adopt feedback-type debriefing. The efficiency of these three teachers' practice remains to be evaluated. We already proved that from the content measured in terms of facets, the lecture is more effective than the summary and the feedback. The lecture also provides more student motivation than the feedback.

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SMALL SCALE VIDEO ANALYSIS OF SCAFFOLDING INCLUSIVE SCIENCE EDUCATION BY GROUNDED THEORY

Simone Abels

University of Vienna, Austrian Educational Competence Centre Chemistry, Austria

Abstract: Grounded theory seeks to uncover latent patterns by constant comparisons of different cases. In the study at hand, patterns in teachers' scaffolding shall be uncovered. Different teaching settings, e.g. IRE (initiation – response – evaluation) discourse and inquiry learning, at an inclusive middle school (grade 5-8), where students with different needs learn together, are demarcated as cases and contrasted to explicate patterns in verbal and non-verbal teaching practices. The aim of qualitatively achieving deep insights into the teaching practices urges to conduct a small-scale study. Thus, an inclusive school was chosen where two different science formats are established to foster all students. The first format is an open inquiry-based interdisciplinary project, where every class works three days a year on individual questions of interest. During the school year 2013/14 nine classes were accompanied by video-based participant observation. The second format is the chemistry education at that school. The eighth grade classes have one hour of chemistry per week in semigroups (maximum of nine students per group). Eight lessons of two semigroups were videotaped, more were planned, but many lessons had to be cancelled during the school year. The pedagogies in chemistry vary from IRE discourse to structured and guided inquiry-based learning. For data analysis video scenes are coded with the program ATLAS.ti where scaffolding strategies are evident, i.e. event-based coding is used. The time scale is not distinct and varies between a few seconds and several minutes. The researcher thereby produces a lot of open codings. These codings are examined for relations to uncover teaching patterns (theoretical codes) in each teaching setting. Codes emerging are, for example, scaffolding self-determined learning vs. self-regulated learning or the prevalence of learning concepts vs. the power of phenomena.

Keywords: Inquiry-based learning, Lernwerkstatt, Chemistry education, Qualitative case study

INTRODUCTION

This paper has a clear methodological focus. It was part of the invited symposium “Scales issues in video analyses of teaching and learning processes” of the ESERA Special Interest Group (SIG) on “Video-Based Research of Teaching and Learning Processes”. This part here is about video analysis conducted by means of Grounded Theory. Video analysis itself is not dictating the mode of data analysis. A systematics has to be chosen in accordance with the research focus how to approach the visual data.

The research focus in this study is inclusive science education, more specifically how teachers scaffold inclusive science lessons. Therefore, a so-called inclusive¹ middle school (grade 5-8) in Austria was found for cooperation where students with different needs learn together. The students are especially different in the diversity dimensions ‘cognitive and physical abilities’, ‘emotional and social background’, ‘language’ and ‘culture’. The school has established many developmental measures to support each student as best as possible, e.g. learning to learn courses, reading support lessons, equestrian vaulting, remedial and physical education etc. In science education there was established a project-based format called *Lernwerkstatt* in German (Puddu, Keller & Lembens, 2012). It is a kind of workshop center originally founded

by Lillian Weber in New York (Weber, 1977). As there is no significant English term, the German word *Lernwerkstatt* is used in the following. The aim of this format is that students work self-dependent on their individually phrased questions of interest. They find the questions being inspired by a room full of materials, objects and phenomena (Abels, 2015; Puddu et al., 2012). As students create their own questions, *Lernwerkstatt* can be considered as an open inquiry format (Blanchard et al., 2010). The aims of inquiry-based teaching are that students learn scientific content, that they learn to do inquiry, and that they learn how to reflect the procedures to understand how science works (Abrams, Southerland & Evans, 2008).

Schools have different ways of implementing *Lernwerkstatt*. It can be integrated in the regular schedule, or it could be an afternoon offer or a once-a-year project. The challenge for teachers during this kind of project is to support each student in accordance with his or her needs and abilities in their 'zone of proximal development' (Vygotsky, 1978). They have to provide scaffolding which can be understood as careful guidance to help students solve scientific problems (Furtak, 2008). Teachers support students to reach the next development level by "giving approval, probing learner's ideas, structuring task activities, and providing general hints or specific suggestions" (van der Valk & de Jong, 2009, p. 832). Blanchard et al. (2010) point out that inquiry-based learning should not be implemented at all without well-structured scaffolding.

Because the scaffolding of teachers is seen as one of the most important conditions for success of a *Lernwerkstatt*, it is the priority of this research project. Latent social patterns should be uncovered in the teaching practice of two science teachers at the cooperation school to know what influences their actions when teaching in an inclusive science classroom. The number of teachers involved classifies the study as small scale. To discover the latent patterns the setting *Lernwerkstatt* was contrasted with the regular chemistry lessons. Different teaching settings were observable in both settings, e.g. IRE (initiation – response – evaluation) discourse and different forms of inquiry learning that are implemented by the teachers as it has shown to be a suitable approach to welcome the diversity of students (Abels, 2015; Scruggs & Mastropieri, 2007). The open inquiry interdisciplinary science project called *Lernwerkstatt* was taught by a team of a biology and a chemistry teacher, and second the regular chemistry lessons taught by the same chemistry teacher, where IRE discourse, structured and guided inquiry took place (cp. Blanchard et al., 2010). Each of these teaching settings is demarcated as a case (Yin, 2009) and the cases are constantly compared to find out different teaching patterns. That means video sequences for each setting are chosen where scaffolding strategies are evident. The research question is: What are the differences in the teachers' scaffolding comparing the different settings?

METHOD

To fulfill the methodological focus, the following main part of the paper will deal with the chosen methodology to analyze the visual data.

Generally spoken, Grounded Theory is applied to study social phenomena and processes to construct theories from empirical data. Main research areas are in social justice, nursing or other societal issues (Strauss & Corbin, 1996). Slowly, it has transferred to the field of education in general and science education in particular. The transfer is possible as teaching is a social, interactive endeavor. Usually, visual data was not considered a source for classic Grounded Theory, but observations and interviews. With increasing technical possibilities and the advantages of analyzing data intensively and flexibly from different perspectives and research foci, video analysis is more and more combined with Grounded Theory (Goldman, 2007; Konecki, 2011). Major techniques like coding, memo writing and theoretical sampling can be applied. "The primary concern is the ability to make constant comparisons of video

data from many activity sequences under varying conditions such that the research can uncover latent social patterns in the substantive field of interest“ (Nilsson, 2012, p. 107).

In the study at hand a constructivist version of Grounded Theory is used which Charmaz (2012, p. 3) distinguishes from Glaser’s classic approach by strategies such as “beginning research with a literature review, making accuracy a central concern, transcribing interviews, and sample size. Glaser and his followers do not explicitly attend to epistemological questions about data collection and quality, research relationships, and researchers’ roles and standpoints.” Three coding procedures are applied to the data: open coding, focused coding and theoretical coding. The first one is used to break the data up and to determine actions, processes and meanings (ibid.). The second step is to find relations between the codings and concentrate on specific aspects that emerge from the data as significant. Hypotheses are developed and tentative interpretations are tested in the data within a case and in contrasting cases (ibid.), i.e. in the same and different teaching settings. Especially, IRE discourse was chosen as a contrast to inquiry learning, because it is a dominant procedure in German speaking countries, but does rather not allow for participation of all students (Markic & Abels, 2014). The aim is to find and refine major categories that capture the core or a pattern of the scaffolding strategies used by the teachers in inclusive science classes.

Applying Grounded Theory to the visual data

In relation to Lemke (2000), Ødegaard and Klette (2012) define three scales of analysis when looking at teaching and learning processes taped on video: the macro, meso and micro level. In their study the macro level is the instructional formats conducted by the teacher. The meso level is the classroom discourse and the micro level is scientific features of language. They emphasize that researchers have to explicit the determination of their used scales and that these scales are “not restricted to time periods” (ibid., p. 183). Nespore (2004) defines educational scales as “spatial and temporal orders” (p. 309); Lemke (2000) additionally sees matter, energy and information transfer as scales. He emphasizes that the “fundamental unit of analysis is a process” (Lemke, 2000, p. 275), which corresponds with the Grounded Theory view (see above). Ødegaard’s and Klette’s (2012) analysis started at a macro level which was becoming more and more fine grained, finishing at the micro level. The analysis in the study at hand also started at a macro level to determine the teaching settings as cases to be distinguished, however, it then continued on a micro level with open coding strategies, looked for focused codings on a meso level, to finally come up with theoretical codes on a macro level again.

The inductive coding procedure is used to work out different scaffolding strategies considering verbal and non-verbal actions of the teachers. A multimodal approach is used (Givry & Roth, 2006). As a scaffolding strategy can last seconds, e.g. using a metaphoric gesture, or several minutes, e.g. asking a series of open questions (see Table 1), event-based coding is applied and no time scale is defined beforehand. This procedure of open coding can be associated with a very detailed and deep, i.e. microscopic, analysis.

Table 1. Results on a micro level by open coding.

Chemistry education	Lernwerkstatt
<ul style="list-style-type: none"> • Phrasing the task • Asking rather closed questions • Asking for subject-specific explanation • Explaining • Using metaphoric gestures • Checking experimental setup • Pointing to lack of time 	<ul style="list-style-type: none"> • Stimulating questions and ideas • Asking open questions • Appreciating/praising students’ questions • Rephrasing students’ ideas • Encouraging to continue work • Suggesting different problem-solving strategies

The next step in Grounded Theory is to find relations between the various codings that emerged before. Thus, focused categories are developed (Charmaz, 2012), e.g. gestures to visualize the submicroscopic level of chemistry concepts (Taber, 2013; see Table 2). This step could be associated with a meso level of analysis.

Table 2. Results on a meso level by focused coding.

Chemistry education	Lernwerkstatt
<ul style="list-style-type: none"> • Targeting goals • Using gestures to visualize the submicroscopic level of chemistry concepts • Creating opportunities to participate by hands-on • Depending on systemic boundaries like curriculum, time, grades etc. 	<ul style="list-style-type: none"> • Orienting on students' input/ welcoming ideas • Using deictic gestures to organize students' work • Creating temporal, spatial, methodical, topical, ... openness • Balancing openness and structuring • Using systemic freedom

After finding and testing these relations on consistency, theoretical codes can surface. In this study, the prevalence of learning concepts vs. doing inquiry is such a theoretical code, another one is the facilitation of participation (for detailed results see Abels, 2015). It can be considered as a result on a macro level (see Table 3).

Table 3. Results on a macro level by theoretical coding.

Chemistry education	Lernwerkstatt
<ul style="list-style-type: none"> • Self-regulated learning • To do inquiry, to learn scientific content (cp. Abrams et al., 2008) • Content-driven (product) • Phenomenological approach to visualize abstract concepts 	<ul style="list-style-type: none"> • Self-determined learning² • To do inquiry, to learn about inquiry (cp. Abrams et al., 2008) • Skill-led (process) • The power of phenomena and materials

The processes on the macro level influence and determine the context for the meso and micro level whereas the actions on the micro level "make possible the repeatable patternings of the next longer scale" (Lemke, 2000, p. 276). This reciprocity makes classroom practice enormously complex to observe and to analyze. In this case here the reciprocity means, for example, that the belief of the chemistry teacher that students need to visualize abstract concepts of chemistry to relate them to their experiences and to understand them, leads to the use of a lot of metaphoric gestures and language.

The following table shows the processes and actions coded on different levels of analysis. The results in each level are interrelated. Spatial and temporal orders are allocated as well. All in all these relations form the scales of research in this study.

Table 4. Scales: the allocation of levels, processes, spatial and temporal orders.

Levels	Processes / Actions	Spatial and temporal orders
Micro level	Scaffolding activities of teacher	Short incidents in teacher-student-discourse
Meso level	Contrasting patterns in teaching approaches	Repeatable patterns in lessons/units
Macro level	Contrasting concepts underlying the activities	Long-term beliefs/logics in a certain teaching approach

Such associations between the levels of analysis (macro, meso, micro) and the proceedings of Grounded Theory are possible and helpful in terms of relating Grounded Theory to visual data.

CONCLUSION

In conclusion, video analysis is a very helpful, flexible, comprehensive way of analyzing data which allows for rich and detailed insights into teaching practices from multiple perspectives. However, video analysis does not tell the researcher exactly how to analyze video scenes systematically. Established analysis procedures can be applied to visual data which is shown above to overcome this gap and make the analysis understandable to others. Thereby, the researcher has to observe certain specifics of the nature of the data. For example, the researcher has to think about how to deal with the complexity of videos: sequential and simultaneous steps of analysis are necessary. Analyses first without sound and then with sound are possible. Another point is that the analysis is possible on different levels of abstraction, i.e. on a macro, meso and micro level. These levels have to be associated to the systematics of the chosen way of analysis. An association between these levels and Grounded Theory was possible (see above). And the researcher has to be explicit about the scales of research applied to the data. This has to be thought through in both the terms of video analysis and in the terms of the chosen way of analysis (see Table 4).

The aspects named so far deal with scales on qualitative level. Additionally, scales could be seen quantitatively. The research study at hand is defined as small scale because of the number of cases; however, large amount of data is produced and intensively analyzed. Maybe these allocations have to be reconsidered or other categories than small and large scale would be more appropriate.

NOTES

1. The school is in Austria where students are separated into different types of school after primary school (age of ten). Therefore, the school can only try to teach in accordance with inclusive principles. As long as there is no joint school for all students, there cannot be real inclusion.
2. Häcker (2007) distinguishes between self-regulated and self-determined learning. While students in the chemistry lessons can sometimes decide on who to work with or which method to follow, they can even decide about their learning goals and topics to work on in the *Lernwerkstatt*, which makes the learning self-determined. This freedom is not given in the regular chemistry lessons as a certain learning goal set in the curriculum has to be achieved.

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