PART 3: STRAND 3

Science Teaching Processes

Co-editors: *Sabine Fechner & Andrée Tiberghien*

CONTENTS

STRAND 3: INTRODUCTION

SCIENCE TEACHING PROCESSES

The contributions to strand 3 “Science Teaching Processes” shed light on current trends in science education research with a focus on the relations between teaching practices and students’ cognitive and affective development. In the majority of cases, the projects report on the design of research-based teaching interventions and their role for learning outcomes. Methods are supposed to embrace multiple approaches including video analysis in science education.

The twelve contributions submitted to strand 3 of the ESERA 2017 ebook consist of eleven accounts on research and development projects from all over Europe and Asia as well as a Swedish teacher workshop that was conducted at ESERA 2017 conference. The eleven research and development papers can roughly be divided into three groups with different foci of investigation: While the majority of papers evaluate a novel or adapted teaching intervention and their impact on students, such as different modes of inquiry-based student activity or differentiated learning environments, others focus on teacher competencies and their progression through interventions or relate teacher beliefs and student outcome with each other. Methodologically, the studies show a diverse scope from case studies collecting and interpreting qualitative data to experimental studies with pre-post-test designs using instruments to measure cognitive and/or affective variables.

In terms of teaching approaches, a slight focus can be found on the evaluation of inquiry-based student activities: While the mode of laboratory activity and its effect on student knowledge is investigated in interdependence with teacher beliefs in two papers (Muth & Erb; Weber et al.), a third contribution focuses on the role of teacher feedback during inquiry-based student activities (Eckes & Wilde). The papers report on data that show the effects of the intervention on student affective and cognitive variables while the intervention itself is not monitored by data collection.

Another three papers investigate novel or adapted teaching approaches with the aim of fostering student affective and/or cognitive outcomes. For teaching at school level, a digital educational scenario is presented that aims at motivating interdisciplinary problem-solving on the basis of gamification (Theodoropoulou et al.), while the approach “Ladders of Learning” adapted from India is examined with regard to its potential as a differentiated learning environment (Hauerstein & van Vorst). For higher education, Kraus and colleagues evaluate a physics course on general relativity which focuses on a model-based and conceptual rather than a mathematical approach (Kraus et al.).

It is interesting to note, however, that these studies investigate students’ responses to a variety of interventions without investigating the implementation of the actual intervention by means of process analysis. The interplay of student and teacher interaction in the learning process is only observed by one paper (Ha & Kim). They examine teachers’ responsive practices to support students’ epistemologically productive practices by means of argumentation analysis. The interdependence of teacher beliefs and student outcome is also investigated in a correlational study using quantitative data (Korom et al.). Here, the relationship of teaching strategies and student reasoning skills is reported.

Focusing on the part of the teacher, one paper reports on multiple studies on teacher topic-specific content knowledge in the area of chemical bonding (Rollnick et al.). Eliciting pre-conceptions, the authors report on ways to diagnose and professionally develop scientifically correct views on the topic.

Concerning the used methods, it is striking that little process analysis, such as video-based analysis in the classroom or intervention group, is used to tackle and explain the learning processes that lead to certain student affective or/and cognitive outcomes. On the other hand, a number of papers pursue the goal of explaining the effects of the intervention on students by directly relating it to teacher beliefs such as the preferred teaching strategy investigated through questionnaires.

The combination of papers also underlines the trend that the selection of specific scientific topics for the investigation is not necessarily justified by the authors. The scientific topics rather become a vehicle to study the respective intervention which is often based on general educational principles (e.g., digital learning, feedback). Exceptions can be found in the course on relativity (Kraus et al.) and the symposium paper on chemical bonding (Rollnick et al.).

Sabine Fechner and Andrée Tiberghien

INFLUENCE OF THE POSTPROCESSING-PHASE OF AN EXPERIMENT IN THE PHYSICS CLASSROOM

Laura Muth and Roger Erb
Institute for Physics Education, Goethe-University, Frankfurt, Germany

The preparation and postprocessing of experiments in the physics classroom and their embedment in the course of the lesson have a great influence on the quality of the lesson (Tesch and Duit, 2004). However, only few studies are concerned with the structure of these two phases. A study by Winkelmann (2015) could prove that learners increase their knowledge during the postprocessing-phase of an experiment. The present study should follow up at this point. Within the framework of a comparative study, it examines the question how the postprocessing-phase of an experiment in the natural science classroom should be structured in order to achieve the best results in the increase of physics knowledge and growth of experimental competencies of students. Therefore, three variations of postprocessing with a different degree of student activity are contrasted. Furthermore, the importance of teachers' beliefs concerning scientific inquiry and the school subject physics for the students' learning progress is evaluated. This field study is designed in a pre-post-test design and conducted in physics lessons in schools to ensure a natural learning environment.

Keywords: science learning, postprocessing of experiments, teacher influence

INTRODUCTION

Research findings of the last years have shown that the experiment plays a major role in the natural science classroom. Not only the conducting-process, but also the preparation and the postprocessing of an experiment have a great influence on the quality of the lesson (Tesch and Duit, 2004). However, research does not provide much evidence on how these two phases of the experiment (preparation and postprocessing) should be designed in order to achieve the best increase in physics knowledge. Still, a study by Winkelmann (2015), who investigated the difference between practical work and teacher demonstrations in the conducting-phase of the experiment, could find out that students also increase their knowledge significantly during the postprocessing-phase. Therefore, it seems interesting to take a closer look at the postprocessig-phase by contrasting several postprocessing situations with different degrees of student activity. As an addition to the competence area of physics knowledge, the development of the experimental competencies of the students should be analysed.

As another result, Winkelmann (2015) could determine the relevance of the interdependency between the experimental situation and the teacher. He could find out that apparently (with a small effect), it is less the experimental situation itself that plays a role, but rather which teacher decides which form of experimentation to use. Therefore, data about teacher beliefs concerning scientific inquiry and the school subject 'physics' is collected in this study, in order to draw conclusions about the role of teachers' beliefs and the interdependency between teacher and experimental situation.

THEORETICAL BACKGROUND

Teacher Beliefs

Teachers and their beliefs have a great influence on the quality of teaching and thus on the learning and the motivation of the students (Helmke, 2012). In an experiment, the activity of the students can vary from simple observations to completely independent work. Thus, the role of the teacher can vary from strongly guiding to loosely supporting. For this reason the beliefs of the teachers on the school subject 'physics' and on scientific inquiry appear particularly interesting. A distinction should be made between teachers with rather constructivist and teachers with rather transmissive beliefs.

In order to categorize the teachers, a questionnaire by Lamprecht (2011) was used, who could identify three types of teachers: the so called instructivist, the constructivist and the mediator. In addition to a different understanding of scientific inquiry, the three teacher types differ in their constructivist beliefs:

1. Instructivist: These teachers emphasize students learning by detailed instructions of the teacher and oppose autonomous learning of students.
2. Constructivist: These teachers emphasize the importance of autonomous learning of students and do not support students' learning by detailed instructions of the teacher.
3. Mediator: Mediators emphasize the importance of autonomous learning of students but do also support students' learning by detailed instructions of the teacher.

Therefore, the instructivist has the strongest transmissive and the constructivist the strongest constructivist beliefs. The beliefs of mediating teachers are positioned in between.

The experimental process

Research on experiments is extensive, but not always consistent. As a basis of the present study, the definition of the natural science experiment according to Millar (2010) is used, who describes the experiment as an activity, '[...] which involves an intervention to produce the phenomenon to be obseved or to test a hypothesis' (Millar, 2010, p. 109 according to Hacking, 1989).

In many studies, the science experiment is split into three phases:

1. preparation or planning,
2. conduction and
3. evaluation or postprocessing.

Regarding the components of the experimental process the *Scientific Discovery as Dual Search* (SDDS) model by Klahr and Dunbar (1988) is used frequently. Klahr and Dunbar (1988) describe the experimental process as a problem solving process. Therefore, an initial state is to be converted into a desired target state through problem solving. This is done in three steps:

1. search in the hypothesis space,
2. testing of hypotheses / search in the experiment space,
3. analysis of evidence.

By considering this and numerous other models, Vorholzer et al. (2016) could identify three central sub-competencies of scientific thinking and experimental techniques that are compatible with the three phases of the experiment (Table 1).

Table 1. Phases of the experiment and related competencies concerning to Vorholzer et al. (2016)

Phase of Experiment	Sub-competencies concerning to Vorholzer et a. (2016)
Preparation-phase	state questions, assumptions and hypothesis
Conduction-phase	plan and carry-out the experiment
Postprocessing-phase	analyse and interpret data.

While research shares the understanding of these central competencies, the associated abilities and skills of the learners are rarely clearly specified or differ enormously. Therefore, the first step of this research project was the conception of a suitable model that concretises the competencies for the postprocessing-phase of a school experiment.

After careful examination of the state of research (Asay and Orgill, 2010; Börlin, 2012; Chinn and Malhotra, 2002; Doland and Grady, 2010; Glug, 2009; Klahr and Dunbahr, 1988; KMK, 2004; Mayer, 2007; Schreiber, 2012), a model was designed which divides the postprocessing-process into three phases. In the first phase the preparation and processing of the measurements data takes place, followed by the formulation and interpretation of results in the second phase. In the third phase, measurement errors are to be considered.

In order to examine whether the developed model was also accepted by experts from theory and practice, it was subjected to a survey involving education experts from universities, school teachers and teachers in training. In this expert survey, three questions should be answered:

1. Are the components of the designed model relevant for the postprocessing-phase of an experiment?
2. Is the model complete?
3. Do teachers and education experts at the universities appreciate the components similarly relevant?

A questionnaire with 19 items was developed in which the experts should assess the components on a 4-level Likert scale with regard to their relevance. 95 experts participated in the survey of which around 3/4th could be classified as scientists from universities (Figure 1).

The survey showed that almost all the components presented were considered relevant by the experts. Two items classified as less relevant were removed from the model, two missing components were added. There were no significant differences in the response behavior between teachers and education experts from universities. The final model of postprocessing competencies of a natural science experiment with the three phases mentioned above and the associated abilities and skills is presented in Figure 2.

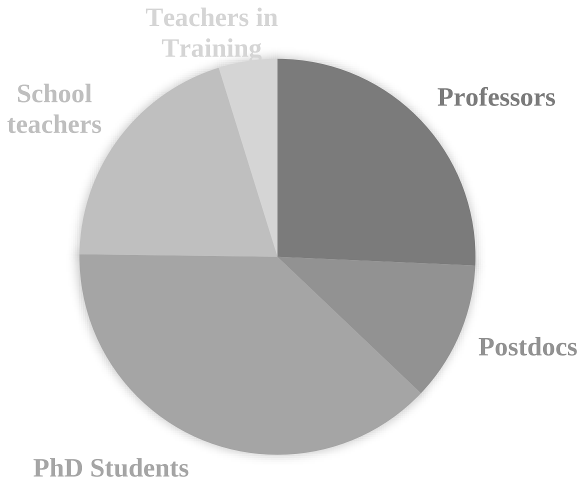

Figure 1. Distribution of the experts on the professions

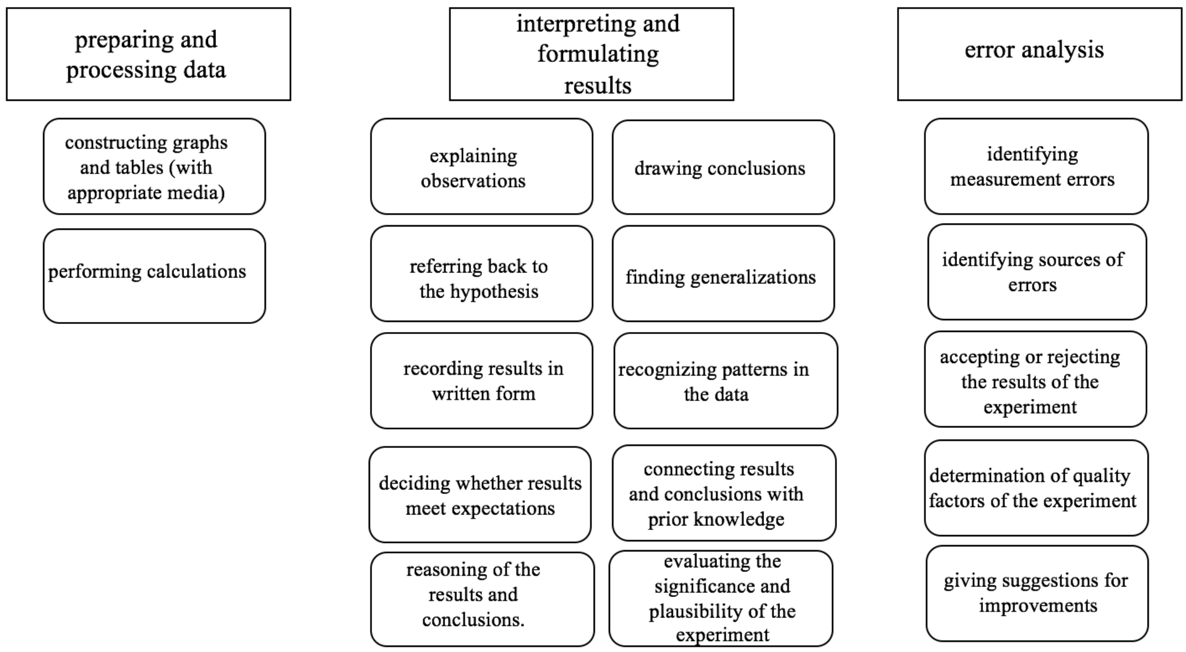

Figure 2. Model of postprocessing competencies of a natural science experiment

RESEARCH QUESTIONS

Building on the findings of Winkelmann (2015), the study covered several research questions, including:

Q1: In how far do postprocessing situations of experiments in the physics classroom with different degrees of student activity affect the development of the students in the areas of physics knowledge and postprocessing competencies?

Q2: What influences do the beliefs of teachers concerning scientific inquiry and the school subject ‘physics’ have on the development of physics knowledge and postprocessing competencies of students?

METHOD

Setting

The study is designed as a comparative study that investigates the development of students' knowledge and competencies through guided and autonomous evaluation of teacher demonstration experiments. It is a quasi-experimental intervention-study in physics lessons in grade seven. A complete randomization could not be realized due to practical reasons. Therefore, the tests and interventions were carried out in the usual classes by the usual teachers. To test the learning effect of the designed lessons, a paired t-test is carried out followed by an Analysis of Variance (ANOVA) to determine possible differences in knowledge growth between the comparison groups. In the ANOVA, the "teacher" and the "postprocessing situation" are fixed factors while the "physics knowledge" and the "postprocessing competencies" are the dependent variables.

Treatments and comparison-groups

To answer the research questions above, three postprocessing situations with different degrees of student activity were developed:

1. Teacher demonstration: The postprocessing-phase is guided and carried out by the teacher.
2. Guided: The postprocessing-phase is carried out by the students in small groups. The students are guided by detailed instructions on work sheets.
3. Autonomous: The postprocessing-phase is carried out by the students in small groups. The process is not guided in any way.

In the conducting-phase of the experiment, teacher demonstrations are realized. Therefore, the study is realized as a 1x3 design with three comparison groups as shown in Table 2.

Table 2. Differentiation between comparison groups by acting party

Treatment	**Phases of the experiment**		
	Preparation	Conduction	Postprocessing
Teacher Demonstration	Teacher	Teacher	Teacher
Guided	Teacher	Teacher	Students
Autonomous	Teacher	Teacher	Students

For reasons of simplicity the first two phases (preparation and conduction) should be referred to as conduction-phase for the rest of the paper.

Course of the study

The study is realised in a pilot and a main study. The pilot study was carried out in winter 2015/2016 with the aim of testing, analyzing and, if necessary, revising the developed measuring instruments. Results of the pilot study can be found in Muth & Erb (2016). In winter 2016/2017, the revised measuring instruments were used to carry out the main survey, in which the students' knowledge increase in the areas of physics knowledge and postprocessing competencies as well as the teachers' beliefs concerning scientific inquiry and the school subject 'physics' were collected.

The intervention comprises ten 45-minute lessons. In the first two lessons the pretest and an introduction are carried out. In this introduction, the teacher performs an experiment as an example with the students. The learners should observe how the teachers plan and carry out the experiment and what steps should be taken during the postprocessing-phase. This is intended to ensure that pupils who are to evaluate the experiments autonomously in the next sessions get an idea of how the postprocessing of an experiment is usually carried out. In the following six lessons, the actual intervention with six experiments takes place. In each lesson one experiment is carried out and evaluated. In the final lesson, the posttest is completed.

Measuring instruments

Table 3 provides an overview of the five measuring instruments used in the main study and their associated application times:

Table 3. Measuring instruments in the main study

Theoretical construct	Authors	Number of Items	Time of Measurement
Teacher beliefs concerning scientific inquiry and the school subject 'physics'	Lamprecht (2011) based on Neuhaus (2004) and Seidel and Meyer (2003)	31	
Cognitive abilities (Q2)	Heller and Perleth (2000)	22	Pretest
Socio-demographic data		5	Pretest
Physics knowledge	based on Winkelmann (2015)	22	Pretest, Posttest, Intermediate tests
Postprocessing competencies	in-house development based on MeK-LSA (2013) e.g. in Dickmann et al. (2013)	19	Pretest, Posttest

In order to be able to allocate the teachers to the three teacher types according to Lamprecht (2011), they complete a questionnaire concerning their beliefs at any time during the intervention.

In the first lesson, the students complete a cognitive performance test and a questionnaire on personal data. This serves to estimate the homogeneity or heterogeneity of the sample afterwards. Since these data is considered to be stable, it is sufficient to collect them at only one measurement time. These tests are followed by a physics knowledge test according to Winkelmann (2015) and a test for postprocessing competencies. In order to be able to differentiate the influence of the postprocessing-phase from the impact of the overall experiment on the physics knowledge increase, the students complete an intermediate test after the conduction but before the postprocessing of each experiment. These six intermediate tests sum up to be exactly the pre or post physics knowledge test. At the third point of measurement, the students complete the questionnaire on physics knowledge and postprocessing competencies again. The three times of measurement are intended to test the learning progress between pre- and post-test (knowledge increase due to the entire experiment) as well as between intermediate tests and post-test (knowledge increase due to the postprocessing-phase).

RESULTS

In total, 376 students in 18 classes (Teacher Demonstration: 6, Guided: 6, Autonomous: 6) with 10 teachers took part in the study. These numbers show that although the sample is satisfactorily high on student side, the number of teachers is still very small with only 10 participants. For this reason, the results concerning the teachers must be interpreted with utmost caution. Among the 10 teachers, four could be identified as instructivists, three as constructivists, and four as mediators. Table 4 shows that not all factor combinations could be filled. Therefore, results on the interaction between teacher and treatment should not be interpreted for the current sample.

Table 4. Distribution of the teacher types on the treatments

	Instructivist	Constructivist	Mediator
Teacher Demonstration	3	1	2
Guided	0	3	3
Autonomous	2	2	2

The results of the t-tests could show that the students increased their physics knowledge in both the conduction ($p < .001$, $\eta^2 = .2$) and the postprocessing-phase ($p < .001$, $\eta^2 = .02$) significantly (Figure 3). A significant increase between pre- and posttest ($p < .001$, $\eta^2 = .02$) was also found in the postprocessing competencies (Figure 4).

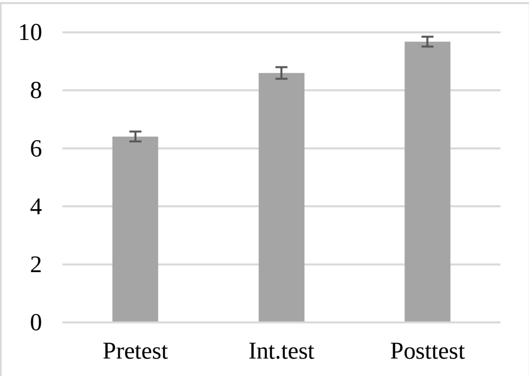

Figure 3. Achieved score in physics knowledge

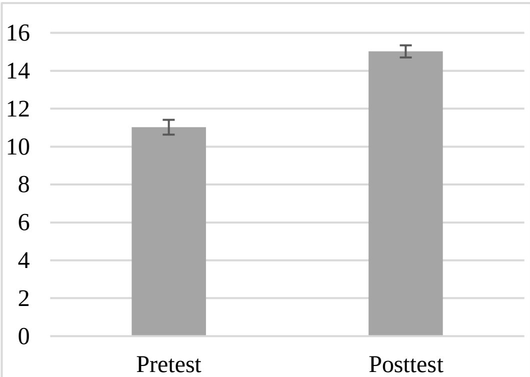

Figure 4. Achieved score in postprocessing competencies

Regarding the treatment, Figure 5 and 6 indicate an advantage for the guided treatment. However, the results of the ANOVA show that the differences in knowledge increase are not significant for both physics knowledge and post processing competencies. The test-power β is sufficiently high.

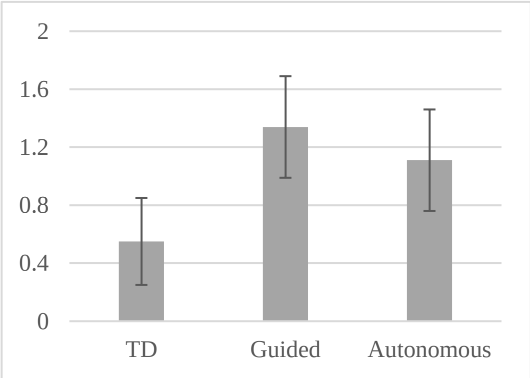

Figure 5. Increase in physics knowledge by treatment

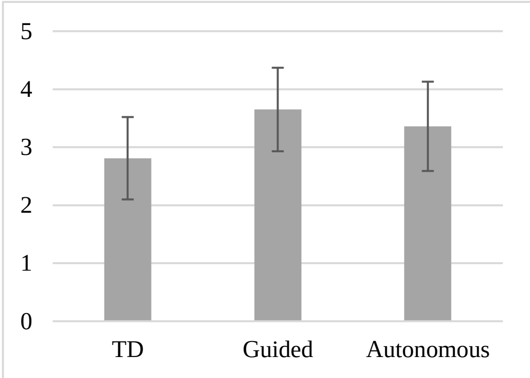

Figure 6. Increase in postprocessing competencies by treatment

In the course of the demonstration experiment, instructivist teachers were able to generate the most growth in physics knowledge, followed by the constructivists ($p < .001$, $\eta^2 = .16$). A contrasting picture is obtained for the postprocessing-phase. In this phase mediators were able to achieve the greatest increase in physics knowledge, followed by constructivist teachers ($p = .001$, $\eta^2 = .035$) (Figures 7 and 8). The differences between the mediators and the other two teacher types are significant in both cases.

With regard to the postprocessing competencies, students with teachers from the mediating type could benefit the most. However, the differences between the three teacher types are not significant in this case. The test-power β is sufficiently high.

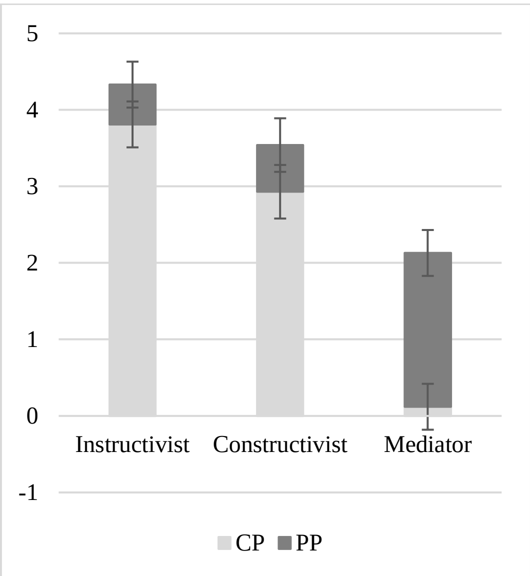

Figure 6. Increase in physics knowledge by teacher in the conduction phase (CP) and the postprocessing-phase (PP) of the experiment

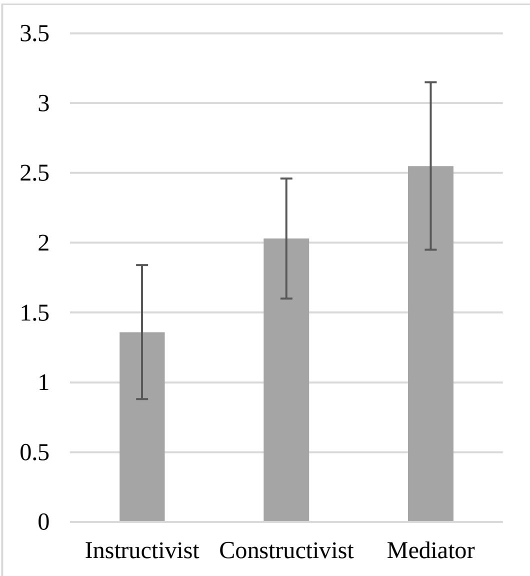

Figure 7. Increase in postprocessing competencies by teacher

DISCUSSION AND CONCLUSION

The results of the t-tests could show, that the designed lessons are beneficial for the knowledge increase for both subject knowledge and postprocessing competencies and that students increase their knowledge significantly during the postprocessing-phase of the experiment. However, the larger effect with $\eta^2 = .2$ could be found in the planning and conduction phase.

With regard to Q1, it can be stated that students who have completed the postprocessing-phase autonomously have been able to increase their physics knowledge and post processing competencies to the same extend as students who have evaluated the experiment together with the teacher. This could mean that teachers should let the student work independently more often. The learners can acquire knowledge just as good as in a teacher guided scenarios, but at the same time autonomous work promotes the development of other competencies (for example social competencies) as well.

For Q2, it could be shown for the present sample that instructivist teachers were particularly successful in the conduction-phase of the experiment. However, mediators were most successful in the postprocessing-phase. Since the actual intervention with treatment variations only took place in the postprocessing-phase, this could indicate that teachers with transmissive beliefs can teach particularly well in teacher-oriented situations (here demonstration experiments), while teachers with both constructivist and transmissive beliefs (=mediators) can respond more flexibly to teaching situations with different degrees of openness. However, it must be stressed here that the sample with only 10 teachers is clearly too small to make generalizable statements. The interpretation can only refer to the present data situation.

It seems worthwhile to carry out further research at this point in order to increase the sample on the teachers. Thus, on the one hand, research question Q2 could be answered more meaningfully, on the other hand an interaction analysis between teachers and treatments could be carried out.

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SUBJECT KNOWLEDGE IN GEOMETRICAL OPTICS: TESTING AND IMPROVING STUDENT'S KNOWLEDGE

Jeremias Weber, S. Franziska C. Wenzel, Jan Winkelmann, Mark Ullrich, Holger Horz and Roger Er
Goethe-Universität Frankfurt, Frankfurt am Main, Germany

In physics education experiments are used quite often and take up a lot of time in the classroom. For something which is as important as this, it is still unclear which kind of experimental situation (ranging from teacher demonstrations to hands-on student experiments) is the best approach to improve student learning. In this project, the following situations were compared: Demonstration experiments done by the teacher, cook-book-experiments done by the students and free-form experiments done by the students. To measure the improvement in subject knowledge, an IRT-scaled test was constructed: Items from previous works were used in a pre-study to estimate difficulty and item-total-correlation. These were then used to construct a pre-post-test study design which was given to ca. 1000 students which were also submitted to the various experiment approaches. Results from previous research suggest that there is an interaction between teacher's concepts, the specific experimental situation and the improvement of subject knowledge: If the teacher uses a situation which fits his own concepts, students improve significantly better. In order to investigate this further, cognitive ability as well as subject knowledge in geometrical optics and current interest in physics was measured. In addition, the teachers were asked to fill out a survey, which should identify their concepts about physics education. First results, based on the data collected so far, will be presented to emphasize for the variegated impact of classroom experiments in physics education.

Keywords: physics education, geometrical optics, IRT

THEORETICAL BACKGROUND

Motivation

Experiments are an important part of many national physics curricula. This is not only grounded in physics as a subject of experimental research, but was also already called for by Wagenschein (1976) and, more current, by Merzyn (2008, 2010). Also, most teachers see experiments as central for science education and assume that they are an important factor for further improvement of subject knowledge and conceptual understanding (Welzel et al., 1998; Abrahams & Millar, 2008).

Therefore, it is not surprising that in a video study, conducted by Tesch (2005), around two thirds of class time in physics lessons is taken up by experiments (with necessary preparations and analyses). Most of the observed experiments were conducted by students, which is also observed by Duit and Wodzinski (2010). Duit and Wodzinski criticize at the same time that students often don't have the time or the opportunity to plan or interpret their experiment but instead use "cook-book lists of tasks" (also mentioned by Hofstein and Lunetta, 2004, p. 47).

In addition, various authors are demanding a more inquiry-based approach to teaching, with less guidance (Bunterm et al., 2014; Hofstein and Lunetta, 2004; Koksal and Berberoglu, 2014; Wodzinski et al., 2007). They argue that more open learning situations demand more cognitive effort of learners, and therefore increase the amount of learning time for the particular subject and hence facilitate better learning. They also believe that open learning situations are more conductive for learning in heterogeneous groups because students can profit from each other and don't have to rely solely on the teacher. Results of flipped classroom concepts, which rely on the same principles, are very positive (Crouch and Mazur, 2001).

But, according to Hofstein and Lunetta (2004) as well as Lazonder and Harmsen (2016), it remains unclear if there is a specific amount or a specific type of guidance in experimental situations which can enhance learning. This was also the result of a previous study by Winkelmann (2015).

Previous Studies

Winkelmann (2015) formulated various experimental situations (demonstration experiments, cook-book-experiments and guided experiments) and investigated their impact on the learning success of students. Those experiments differed in the amount of guidance during planning and execution and which person would conduct the experiment, as seen in the following table.

Table 1. Description of experimental situations

	Experimental situation		
	Demonstration	Cook-Book	Guided
Planning	Teacher	Teacher	Students
Execution	Teacher	Students	Students
Analysis	Plenum	Plenum	Plenum

All experiments had light refraction as a topic, especially the following phenomena:

a) Refraction of light on a water surface,
b) Refraction of light on a glass surface,
c) Total internal reflection in glass,
d) Focusing of light in lenses,
e) Image formation in lenses.

Winkelmann (2015) reported that the student experiments had no significantly different impact on the students' learning success, compared to the demonstration experiments. At the same time, he found a small interaction between the experimental situation and the teacher who conducted it. He also found a small advantage for students with high and low abilities in experimental situations with strong guidance, compared to students with medium ability, which profited more from open experimental situations.

Research questions

Based on the motivation and the previous studies, the following research questions were formulated:

1.1. What impact have different experimental situations in physics classes on subject knowledge?

1.2. What differences can be shown in heterogeneous learning groups due to the different experimental situations with regard to subject knowledge?

2. What impact has the interaction between characteristics of the teacher and the experimental situation on subject knowledge?

METHOD

Study design

To answer these research questions, a study called "Testing and improving student's competencies in diverse learning groups by using an experiment-based physics curriculum" (funded by the German Federal Ministry of Education and Research) was proposed.

Three different experimental situations were chosen to be compared: Teacher demonstration, small group practical work with detailed instruction (Cook-book-experiments) and small group practical work with little instruction (Guided). These situations were the same experimental situations as in the previous study by Winkelmann (2015). The three treatment groups were respectively composed of randomly assigned classes. An overview of the length of the Pre-, Post- and Post-2-Tests (Follow-Up-Test) as well as the whole study duration, can be found in the Table 2:

Table 2. Overview of study structure and measurement dates

2 lessons	12 lessons	2 lessons	2 lessons
Pre-test	Intervention/ Experiment	Post-test	Post-2-test
September 2016	October-December 2016	January 2017	February/March 2017
Group 1: Teacher demonstration			
Group 2: Small group practical work with detailed instruction			
Group 3: Small group practical work with little instruction			

For the Post-2-Test a Planned-Missing-Design (Little & Rhemtulla, 2013) was used. In this, not all participants are tested at every measurement date, but only on one of the three Post-2-Tests and therefore participants completed three of the five overall tests. The participants, still grouped in classes, were randomly assigned to the different measurement dates. This is deemed appropriate, due to the sample size, which is large enough to ensure satisfactory test power.

Measures

In the pre-test, students' sociodemographic characteristics as well as students' subject knowledge were measured (CAT-V3, -N2, Heller & Perleth, 2000) to estimate the heterogeneity of specific classes.

At the same time the teacher's characteristics were determined (Lamprecht, 2011). The results of this questionnaire should give insight in the beliefs about teaching and the science of physics of the various teachers. Those beliefs are suspected to impact how teachers teach and therefore give an idea about which experimental situation could be the best fit for their respective teaching style.

In the post-test the students are asked about their current interest in physics (Schulz, 2011). The answers to this particular part of the questionnaire can lead to a deeper understanding which experimental situation is most motivating for students as this is one of the goals of using experiments (Merzyn, 2008, 2010).

To measure a potential nonlinear development of the subject knowledge and scientific literacy, tests for those areas were administered at all five measurement dates. To measure the scientific literacy an already existing IRT-scaled test by Glug (2009) was used. To measure the development of the subject knowledge a new IRT-scaled test was constructed, drawing on Winkelmann (2015). The development of these two areas is not only important to answer the research questions but are also important indicators for the individual growth of the student's competencies.

Construction of an IRT-scaled subject knowledge test (geometrical optics)

As a first step, the 44 items which Winkelmann (2015) used in his study were analyzed with models of the Item-Response-Theory (van der Linden & Hambleton, 2013). By using Winkelmann's data, the item difficulty could be scaled and the personal ability estimated. By checking various psychometric criteria, the items were reviewed for their usability in the study. These criteria were Itemfit, Item-Total-Correlation and differential item functioning for gender (Osterlind & Everson, 2009). 33 items were selected for the item pool, but those were generally rather difficult. For this reason, 33 additional items with intended lower performance requirements were developed by an expert group.

In a second step, the 33 new items, together with 18 previously selected items, were used in a pre-study with 301 participants. To get as many participants as possible, the test time has been minimized by using a balanced incomplete booklet design (Frey, Hartig & Rupp, 2009). The resulting data was again reviewed using models of IRT, in the same way as mentioned before. The item analyses (selection by using the aforementioned criteria) lead to a total item pool size of 60 items (out of 66 items overall), which were available for the construction of the subject knowledge test.

Test-Booklets for all measurement points were constructed in a third step. To minimize repetition and to adapt test difficulty according to the levels of students' learning progress, only a part of the items was used during each measurement point. Every booklet included a set of anchoring items (which were repeated at two dates) and date-specific items. This approach permits to match the ability estimation of students over the three times of measurement without using the exact same items.

FIRST RESULTS

After reviewing the results from the main study, data from 44 teachers and 1094 students were analyzed. The average class included 25 students, ranging from 14 to 31 students. The students were averagely 14 years old. Students were mostly in the seventh grade (73%), but more than a quarter of the students were in the eighth grade (27%). Of the 978 students who indicated their gender, 49% were male students and 51% were female students.

Subject Knowledge

The subject knowledge was measured before and after the different treatments. In all treatment groups the subject knowledge of the students grew after the treatment significantly and with a sizeable effect (partial $\eta^2 = 0.365$). It should be mentioned that the estimated ability of the students was highest directly after the treatment and afterwards declined slightly. The treatment group who experienced the teacher demonstration experiments differed at the pre-test measurement date slightly from the other groups (cohen's d = 0.21 between Demonstration group and Guided group and cohen's d = 0.29 between Demonstration group and Cookbook group), but this difference stayed unchanging over all measurement dates and was therefore not influenced by the treatment itself.

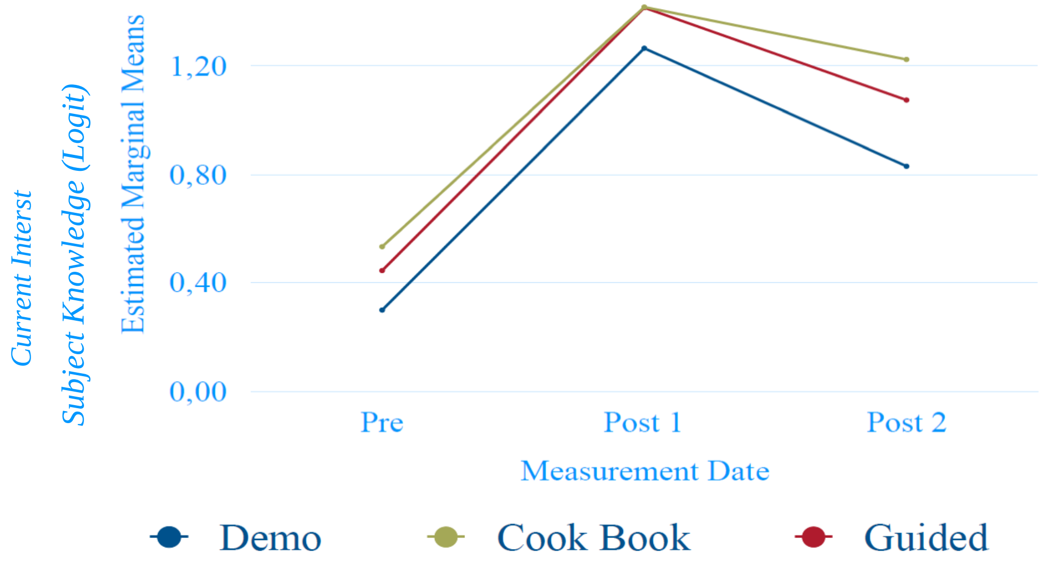

Figure 1. Development of subject knowledge (estimated ability) of students in all treatment groups

No significant difference could be found in the growth of the estimated ability of the students between the treatment groups. As seen in Figure 1, the overall progression in the estimated ability in the area of subject knowledge seems to be similar for students of all treatment groups.

It should be noted, that the sample size for this analysis consisted of 867 students after eliminating all non-complete data sets (Demonstration group: 302, Cookbook group: 291, Guided group: 274). The difference between the Cookbook group and the Guided group, which seems to emerge at the time of the Post-2-test was significant, but very small (partial $\eta^2 = 0.02$).

Current interest

Subsequent to the intervention the students were asked to rate their current interest for physics on a five point Likert scale, from “uninterested” up to “interested”. While this doesn't have a significant difference for male students over all treatment groups, female students show a significantly different interest between the Demonstration group and the two other groups can be seen in Figure.2.

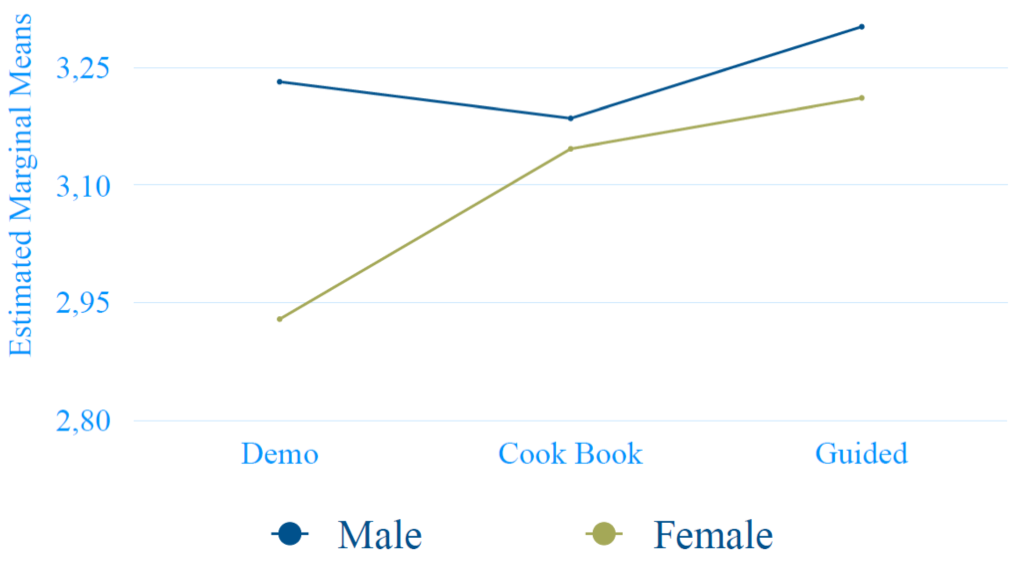

Figure 2. Current interest of students in all treatment groups, divided by gender

The difference between male and female students is insignificant when both were part of a treatment group who did student experiments. Female students showed no differing interest after conducting student experiments with more or less guidance. However, the difference between male and female students in the Demonstration group is significant and has a moderate effect size (cohen's d = 0.38, $p < 0.05$).

To further analyze these findings, the ratio of male to female teachers in each treatment group was examined. This showed no significant deviation in the ratios of male to female teachers over all treatment groups.

Due to the elimination of incomplete data sets, the sample size in this analysis consisted of 978 students.

CONCLUSION

Findings

As found in previous works, the subject knowledge rises after the treatment, but no significant difference was between the treatments. At this point, it can be concluded, that experiments with very low guidance have no significant negative impact on the learning success of students, in comparison to situations structured by the teacher. This is important because most teachers prefer more structured learning environments to closely control the learning outcomes. As no significant advantage of one experimental situation could be found, it is doubtful if the learning success in the area of subject knowledge could be the deciding factor to choose one experimental situation over another.

More importantly, current interest is closely related to positive and open engagement with the subject and therefore is believed to be conductive for better learning (Merzyn, 2008, 2010). As student experiments elicited a significantly higher interest from female students, this should be an important factor in the teacher's decision for or against a particular experimental situation.

Further analysis

At the moment, the data is still being analyzed. Further work should deliver a more in-depth analysis of the first results which are reported here.

The data will be analyzed:

a) On interactions between teacher's characteristics and the experimental situation and the impact on subject knowledge,

b) On interactions between class heterogeneity and the experimental situation and the impact on subject knowledge,

c) On interactions between teacher's characteristics and the experimental situation and the impact on conceptual understanding,

d) On interactions between class heterogeneity and the experimental situation and the impact on conceptual understanding.

This will be done by using multilevel analyses to provide for the nested structure of our data.

Future Research

The subject knowledge test which was constructed for this study can be used in other IRT research settings. After the main study, most items showed a good quality, only 4 of the 12 anchor items and 7 of the other 36 items had to dropped, due to item misfit. By using data from this study, the item difficulty could be estimated and it is mostly of a moderate difficulty.

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THE BENEFITS OF STRUCTURING TEACHER BEHAVIOR IN BIOLOGY LESSONS WITH EXPERIMENTS

Alexander Eckes and Matthias Wilde
University of Bielefeld, Bielefeld, Germany

Experimentation is among the methods of inquiry in biology, and it is the most important form of scientific inquiry. The corresponding scientific problem-solving can be framed by the central elements that are posing questions, establishing hypotheses, planning the experiment and interpreting the findings. In this study, this problem-solving is framed through scientific discovery learning. Conducting experiments in class may pose challenges. Students may fail in selecting relevant information, and they may in turn become confused, lost and frustrated. Being potentially unable to effectively or successfully interact with the working materials in the learning environment might lead to students perceiving themselves as not competent. Competence, alongside autonomy and relatedness, is one of the three basic needs of the Self-Determination Theory of Motivation (Deci & Ryan, 2002; Ryan & Deci, 2017), and the fulfilment of the three needs is related to positive qualities of motivation. The need for competence is the focus of this study. As it is an invaluable tool in guiding students through discovery settings, feedback was used to structure teacher behavior. Feedback can support students' perception of competence. Supporting students' competence may balance the requirements of scientific inquiry and students' abilities. We hypothesized that informative tutoring feedback facilitates positive qualities of motivation and knowledge acquisition. In a pre-post-design, this study aimed to investigate the effects of basic and informative tutoring feedback (cf. Narciss 2004, 2006) on motivation and knowledge acquisition. 183 high school students from sixth and seventh grade (M_{age} = 12.02 years, SD_{age} = 0.68 years) from schools of medium and high stratification levels took part in the study. Students received an introductory lesson as well as two consecutive lessons on experimentation. Students' motivation was assessed using an adapted version of the Intrinsic Motivation Inventory (IMI; Ryan, 1982). Reliabilities of the subscales were satisfactory and ranged from Cronbachs α = .67 to α = .85. Offering informative tutoring feedback showed beneficial effects on intrinsic motivation. Findings for knowledge acquisition were not conclusive.

Keywords: feedback, motivation, discovery learning

INTRODUCTION

Scientific discovery learning

This study uses Bruner's (1961, 1970) approach to discovery learning, as it provides a framework for experimentation in an open learning environment. More specifically it focusses on scientific discovery learning and infers to conducting experiments as the central characteristic (de Jong & van Joolingen, 1998). Experiments are the most important method of scientific inquiry, as they develop scientific discovery learning environments through framing of the central elements of scientific problem-solving by posing questions and hypotheses, planning experiments and interpreting the findings (Abd-el Khalick et al., 2004; Koslwoski, 1996; Klahr, 2000; Hammann 2004). The open discovery environment enables students to work independently and self-determined, yet it may also put extra strain on students (Tuovinen & Sweller, 1999). Central elements of scientific problem-solving may pose problems to students, through which they might not be able to work effectively. Problems such as not being able to choose relevant information (Mayer, 2004) may occur. Thus, students may not feel competent while working on the respective task at hand, and might become frustrated and confused (Brown & Campione, 1994; Hardiman, Pollatsek, & Weil, 1986).

Structure

To manage the potential problems mentioned above, teachers can apply structure to support students working on scientific inquiry in an open learning environment. Teachers can facilitate structure by providing clear, comprehensible, explicit and detailed instructions through setting clear expectations by initiating the students' activities with an action plan and by giving students constructive feedback (Brophy, 1986; Skinner & Belmont, 1993; Skinner et al., 1998). Structure can be viewed as a continuum ranging from chaos to high degrees of structure (Jang, Reeve, & Deci, 2010). Teachers facilitating chaos do not communicate clear rules and expectations, or how to accomplish these expectations. This may make things unclear for the students. Provisions of structure can be used by students to better choose tasks that may be well suited to their abilities and their competence (Ryan & Deci, 2002). In this way structure might support scientific inquiry.

Feedback

Feedback has been shown to be an effective tool in discovery settings (Kirschner, Sweller & Clark, 2006; Moreno, 2004). This study focuses on feedback as a provision of structure to guide students in such a setting. Taking Hattie and Timperleys (2007) analysis into account, feedback is one of the ten major determinants of achievement. Feedback provides students with information that allows them to verify their current working practice as well as the correctness of their responses. This can enable them to improve their thinking and behavior, and facilitates better learning performance (Shute, 2008). Here, informative tutoring feedback was implemented to provide students with strategic information on how to complete the tasks at hand, and how to apply efficient strategies (Narciss, 2004, 2006). Components of strategic information may be: cues for retrieving facts, analogies, hints on possible sources of information, hints on errors and successful strategies as well as Socratic questions (Narciss, 2004; Narciss & Huth, 2004). Feedback can have an impact on students' perceived competence (Connell & Wellborn, 1991; Grolnick & Ryan, 1987; Jang et al, 2010; Taylor & Ntoumanis, 2007). According to the Self-Determination Theory of Motivation (SDT) (Deci & Ryan, 2002) this can affect students' quality of motivation.

Self-Determination Theory of Motivation

SDT describes a continuum that distinguishes two types of motivation, extrinsic and intrinsic motivation. Extrinsic motivation can be observed in behaviors that are conducted with instrumental intent (Deci & Ryan, 1993). In contrast, intrinsic motivation is autotelic and defined by curiosity, exploration, spontaneity, and interest in the task itself (Deci & Ryan, 1993). SDT states that competence, autonomy and relatedness are the three psychological needs that are inherent to every human being. Relatedness is the need to feel connected to and accepted by significant others. Feelings of autonomy arise when the locus of causality is internal, and actions are based on an inner desire for self-determination (Reeve, 2002; Ryan &

Deci, 2002). The need for competence represents the need to feel effective and to successfully interact with one's surroundings (Deci & Ryan, 2002; White, 1959). It is satisfied when a balance between ability and requirements is met (Danner & Lonky, 1981; Deci & Ryan, 1993). The satisfaction of these three needs is essential to fostering positive qualities of motivation (Deci & Ryan, 2002).

In this study, informative tutoring feedback is utilized to facilitate competence in students. Working on tasks that correspond to a person's abilities in compliance with the requirements of a task may influence the satisfaction of the basic need for competence (Grolnick & Ryan, 1987; Skinner et al., 2008) and in turn might contribute positively to intrinsic motivation (Ryan & Deci, 2002).

Learning in scientific discovery learning

Scientific discovery learning is likely to increase the personal relevance of a subject matter as actions are undertaken in a self-determined manner, thus supporting perceptions of autonomy. There is very strong evidence to suggest that support in autonomy leads to performance gains (Boggiano, Flink, Shields, Seelbach, & Barrett, 1993) and conceptual understanding (Benware & Deci, 1984; Flink, Boggiano, & Barrett, 1990; Grolnick & Ryan, 1987; McGraw & McCullers, 1979). In addition, offering feedback and thus supporting competence can lead to positive qualities of motivation. Satisfying the basic needs for competence and autonomy can lead to self-determined, motivated students that can acquire more differentiated knowledge and are better able to apply it (Deci & Ryan, 1993). This can lead to more intense contact with the subject matter as well as a deeper understanding of the subject matter acquired during the problem-solving processes (Bruner, 1961).

The aim of our study was to investigate the effect of two degrees of structuring feedback –basic and informative tutoring feedback – on students' intrinsic motivation and knowledge acquisition in biology lessons with experiments.

HYPOTHESES

Informative tutoring feedback can help facilitate structure in biology lessons with experiments by enabling students to interact with the tasks in the scientific discovery learning environment in a meaningful way. Therefore, feedback is assumed to facilitate students' perceived competence. Support for perceived competence may promote positive qualities of motivation.

H1: In biology lessons with experiments, positive qualities of motivation can be facilitated to a higher degree through informative tutoring feedback rather than basic feedback.

Scientific discovery learning might support positive qualities of motivation in problem-solving processes through perceptions of autonomy, personal relevance and engagement with the materials. Students may then achieve more intense contact with the task, leading to deeper understanding (Benware & Deci, 1984; Boggiano et al., 1993; Müller & Palekčić, 2005) and a more in-depth examination of working materials, which can lead to higher knowledge gains (Deci & Ryan, 2002).

H2: In biology lessons with experiments, knowledge acquisition can be facilitated to a higher degree through informative tutoring feedback rather than basic feedback.

METHOD

Sample

The sample consisted of 183 students (91 females, M_{age} = 12.02 years, SD_{age} = 0.68 years). Participating students were in grades six and seven and were from schools of medium and higher types of tracking. In this quasi-experimental study, classes were randomly assigned to the control group “F” (n=102) in which teacher trainees offered a basic level of feedback, or to the experimental group “F+” (n=82) in which teacher trainees offered informative tutoring feedback. In both treatments teacher trainees worked in tandem. The teacher trainees were biology students of advanced semesters. All of them were trained in several meetings prior to the intervention in providing feedback and in the autonomy-supportive teaching style. In this study teacher trainees were deliberately chosen over the students` regular biology teachers for several reasons. Teacher trainees show interest in new teaching strategies and have not yet established strong teaching habits (Hoy & Woolfolk, 1990). More experienced teachers tend to use rather defined styles of teaching which may vary greatly. In contrast, teacher trainees have just begun to develop their own teacher personality. Most importantly, teachers and teacher trainees may differ in respect to offering feedback. Teacher trainees’ feedback seems to be very valuable (Cho & Schunn, 2007), whereas expert feedback can be perceived as less helpful or even hard to understand (Cho & Schunn, 2007).

Study design and treatment

This study examined problem-oriented experiments in an open environment with the topic of bird flight in biology lessons. Emphasis was put on formulating and testing hypotheses, analyzing data and drawing conclusions (cf. Abd-el Khalick et al., 2004). Experimentation as a method was chosen deliberately in this study as it offers plenty of situations to offer feedback while students work on the experiments. Students used an experiment set containing an abundance of possibilities for experiments on bird flight. Students used a flow chart to frame each of their experiments. The flow chart was adapted from Walpuski and Sumfleth (2007) and was created to visualize the steps of scientific reasoning. It depicts scientific reasoning in the form of a circle, starting at a problem and continuing along the steps of inquiry, leaving room for students’ notes. The intervention consisted of three lessons. Students participated in an introductory lesson, in which an experiment (thermal lift) was demonstrated by the teacher trainees. This experiment and the corresponding scientific reasoning was explained using a flow chart for the experiment. The introductory lesson was followed by two lessons in which students conducted experiments in groups of three to four students. In both treatments students worked together with their teacher trainees to form research questions or hypotheses. They chose which experiments they wanted to work on, planned the experiments themselves, worked independently on the experiments they chose, evaluated their findings and drew conclusions. The interpretation was finally checked with the class and the teacher trainees at the end of the lesson. Classes were randomly assigned to the control (F) and to the experimental treatment (F+). In both treatments feedback was given if students asked the teacher trainee or because it was obvious to the teacher trainee that a group had problems. In the basic feedback treatment (F), students were given the necessary information and expectations needed to work properly. Basic feedback was defined by teacher trainees in such a way that if a group had problems working on one of the experiments, the teacher trainees promoted discussion inside the respective group without the further involvement of the teacher trainees. If the problem persisted, teacher trainees suggested that students might work on another experiment and that problems were going to be discussed at the end of the lesson. In the informative tutoring feedback (F+) treatment, students received informative tutoring feedback (Narciss, 2004), providing information about students' performance and error correction information. Teacher trainees asked students first about their current position on the flow chart. Then the feedback was specifically given corresponding to the current position on the flow chart continuously, using clear explanations of working materials. To elaborate on the aspect of tutoring, the reflective toss (Van Zee & Minstrell, 1997) was used. It is defined as a sequence consisting of a student statement, a teacher question and a student elaboration. In a reflective toss, the teacher's question tries to "catch" the meaning of the student statement and "throws" the responsibility for thinking back to the student (Van Zee & Minstrell, 1997). In using the reflective toss, teachers encourage students to elaborate independently on their own questions, making their thinking more visible and allowing teachers to use it as the basis for adaptive feedback.

Questionnaires

This study used a pre-post-test design. Questionnaires used a five-point rating scale that ranged from '0 - not at all true' to '4 - very true'. Internal consistencies were reported as Cronbach's α. Students' self-determination in biology lessons was assessed in the pre-test using an adapted version of the Academic Self-Regulation Questionnaire (SRQ-A; Ryan & Connell, 1989; 4 subscales) to check for potential differences in regulation types between treatment groups. The Relative Autonomy Index (RAI) was derived from the subscales of the SRQ-A: *intrinsic* (5 Items, α = .88), *identified* (4 Items, α = .82), *introjected* (4 Items, α = .70) and *external* (4 Items, α = .48). The RAI provides an indicator of whether a child is working autonomously or controlled during regular biology classes at school. Additionally, a knowledge test consisting of five multiple choice items was assessed in the pre-test.

In the post-test, an adapted version of the Teacher as a Social Context Questionnaire was used (TASCQ; Belmont, Skinner, Wellborn, & Connell, 1988). The TASCQ (13 Items, α = .88) examined the implementation of structure. Additionally, an adapted version of the subscales *interest/enjoyment* (7 Items, α = .85), *pressure/tension* (5 Items, α = .67), *perceived choice* (5 Items, α = .67) and *perceived competence* (6 Items, α = .79) of the Intrinsic Motivation Inventory (IMI; Ryan, 1982) was used. The knowledge test was applied again in the post-test.

RESULTS

In this study, the effect of basic and informative tutoring feedback on the motivation and knowledge acquisition of the students was examined. The data was assessed using analysis of variance.

To assess the operationalization of feedback, we tested the implementation of teacher structure using the TASCQ in the post-test. The students of treatment F+ perceived a significantly higher degree of structure than the students in the F treatment ($F(1,174) = 20.807$, $p \leq .001$, $\eta^2 = .107$).

The provision of informative tutoring feedback was perceived as being more structured than the basic feedback.

To test for potential motivational differences between the two treatment groups, the Academic Self-Regulation Questionnaire (SRQ-A) was used in the pre-test. Derived from the four subscales of the SRQ-A, the Self-determination index (SDI) was calculated (Ryan & Connell, 1989). Analysis showed that there was no difference between the treatment groups (F(1,149) = 0.031, p = ns). Both groups showed similar motivational pre-conditions regarding biology lessons.

To examine motivation, the Intrinsic Motivation Inventory (IMI) was assessed in the post-test. Four subscales were used. The i*nterest/enjoyment* subscale can be considered the self-report measure of intrinsic motivation. The *perceived choice* and *perceived competence* are positive predictors, whereas the *pressure/tension* subscale is a negative predictor of both self-report and behavioral measures of intrinsic motivation. The analysis of the IMI revealed that students provided with informative tutoring feedback perceived themselves as more competent and perceived more interest and enjoyment as well as less pressure while working on the experiments (table 1). For the subscale *perceived choice*, we found no difference between basic and informative tutoring feedback (Table 1).

Table 1. Mean scores (M) and standard deviations (SD) for subscales of the IMI are shown separately for basic feedback (F) and informative tutoring feedback (F+). Results of an ANOVA for each of the subscales of the adapted IMI follow. P-values are reported in the following α levels: p < .001, p < .01, p < .05 and not significant (ns), p > .05. Effect sizes are reported as partial eta square (η^2).

subscale	treatment	*M (±SD)*	main effect feedback
Perceived competence	F	2.74 (±0.85)	F(1,174) = 10.43, p < 0.001, η^2 = .057
	F+	3.10 (±0.57)	
Interest/ enjoyment	F	2.69 (±0.91)	F(1,174) = 4.30, p < 0.05, η^2 = .024
	F+	2.97 (±0.81)	
Pressure/ tension	F	1.07 (±0.77)	F(1,174) = 4.41, p < 0.05, η^2 = .025
	F+	0.82 (±0.80)	
Perceived choice	F	2.81(±0.84)	F(1,173) = 1.83, p = ns
	F+	2.97 (±0.65)	

For the analysis of the knowledge tests assessed on pre- and post-test a mixed ANOVA was used. The descriptive data showed that the treatments F (M = 11.58, SD = 2.79) and F+ (M = 13.27, SD = 2.68) already differed in the pre-test. These differences are repeated in the post-test F (M = 13.91, SD = 2.62) and F+ (M = 14.69, SD = 2.84). The results for the mixed ANOVA were: Main effect for time (F(1,163) = 49.00; $p \leq 0.001$; η^2 = .231), main effect for treatment (F(1,163) = 13.90; p ≤ 0.001; η^2 = .079) and interaction (F(1,163) = 2.92; p = 0.09; η^2 = .018). Students did acquire knowledge regarding bird flight. The interaction is marginally significant.

The rather small effect size suggests that there might be an interaction between knowledge gain and treatment.

DISCUSSION AND CONCLUSION

The preliminary results showed that the operationalization of structure using feedback was effective. The large effect for informative tutoring feedback is in line with the importance that can be deduced from the meta-analysis of Hattie and Timperley (2007), putting feedback in the top ranking influences on achievement. This study succeeded in creating a very effective form of teacher instructional structure in the form of informative tutoring feedback. Additional teacher structure had a positive effect on three of the four subscales that were used to measure intrinsic motivation. Informative tutoring feedback led to higher support in *perceived competence* as well as *interest/enjoyment* in comparison to basic feedback. The subscale *perceived competence* was the most prominent one and can be directly linked to structure (Connell & Wellborn, 1991). The *interest/enjoyment* subscale is considered the self-report measure of intrinsic motivation. Students, in addition, perceived less *pressure/tension* when supported by informative tutoring feedback. The subscale *perceived choice* showed no effect for provision of teacher structure, which is not surprising as the scale is related to autonomy, which was constant in both treatments. Using informative tutoring feedback and structuring the lessons beforehand motivated students to a significantly higher degree in comparison to support through basic feedback. The first hypothesis can be supported. The results of the perceived competence subscale of the IMI notably suggest that the effect of informative tutoring feedback is achieved through students' perception of competence while working on experiments in an open learning environment.

Without taking the treatment into account, the results for the knowledge test showed knowledge gains for participating students. There were already differences between both treatments in the pretest. In the pretest students in treatment F+ scored higher than those in the treatment F. These differences have to be taken into account for the interpretation of the interaction between treatment and time. The result for the interaction suggests that there may be a dependence of knowledge gain regarding affiliation to the basic or informative tutoring feedback treatment. The interaction is marginally significant and shows a small effect size. The differences between both treatment groups in the pretest may impact the results of the interaction and must be considered. A follow-up study with a larger sample size is needed to analyze the connection between the provision of feedback and knowledge acquisition.

The results of the study suggest that the provision of informative tutoring feedback was more effective and led to significantly higher perception of competence, higher interest and enjoyment as well as lower perception of pressure and an unimpeded perception of choice. The knowledge test showed an overall knowledge gain for both treatments and evidence for an interaction between the factors provided feedback and time.

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ARCHIMEDES AND THE TIME MACHINE: A DIGITAL EDUCATIONAL SCENARIO OF A.R.G.

Christine Theodoropoulou[1], Yannis Psaromiligos[2] and Symeon Retalis[3]
[1]Platon I.B. World School, Athens, Greece
[2]Technological Education Institute of Piraeus, Athens, Greece
[3]University of Piraeus, Athens, Greece

The current study presents an Alternate Reality Game, designed for 4th Graders, as a form of formative evaluation of Competences developed through the school year. The story of Archimedes engages students in a journey in time and space. Their journey involves collecting clues in real world activities, but also accessing information from the internet through their tablets. This playful digital educational scenario is based on transdisciplinary learning, linking astronomy, math, language and history, while the Greek Curriculum is interrelated with I.B. learner skills in the P.Y.P. Students apply Competences and exercise Life Skills, such as critical thinking, organizing information and relationship management while working in active gaming. Finally, the game leads to a straightforward invitation to participate in a continuum of gamification lead by the students. The assessment of this educational scenario is based on class observation. Problem solving situations, Internet applications, and scaffolding procedures created a unique experience for the students. Students beginning from level 'Comprehend' of the reversed pyramid of Bloom's Taxonomy were led to level 'Create' by encouraging students to create their own riddles and to document their own ideas for a new game hence the continuum.

Key words: alternate reality games, cooperative learning, competences

BACKROUND

Alternate Reality Games (A.R.G.) fall into the category of digital games and is an interactive networked narrative that uses the real world as a platform and employs transmedia storytelling to deliver a story that may be altered by players' ideas or actions. (Szulborski, 2005). 'The Beast', the first A.R.G., was created in 2001 for marketing promotion for the movie A.I. (Artificial Intelligence) (McGonigal, 2007). Ever since A.R.G. are famous, not only for their originality but also for their educational value. They engage players in various interactive and teamwork challenges with riddles that gradually unfold a storyline.

The current study presents the development of an A.R.G. with an inter relation between Greek Curriculum and I.B. learner's skills in the P.Y.P. There is also a strong interdisciplinary thread linking astronomy, math, language and history. This educational scenario was developed and assessed through classroom observation.

METHODOLOGY

Development and context

'Archimedes and the time machine' is based on competences (Sigrid Blömeke, 2013) and was originally addressed to 4th Graders, though eventually 5th Graders participated as well. Students were interfaced with A.R.G. and mobile devices in classroom for the first time. The implementation of the game took 3 teaching hours, which is approximately one and a half hours. It was designed according to the principles of Instructional Scaffolding Learning and it demands of students working in groups. Ii is significantly important to mention in that it was designed as a formative assessment tool and does not intent to teach students new knowledge. Therefore, learning objectives of the 4th Grade are mainly to be found in the context of the game. A.R.G. took place in 'Platon I.B. World school', a co-operatively- based environment that apply the cooperative method Jigsaw (Aranson, 1992).

Aim of the study

The present study aims to develop, implement and assess an Educational scenario. The assessment was based on class observation. Therefore, five teachers participated in the implementation of the A.R.G.

THE PLOT

The game begins with the narration of Archimedes' story, without letting students know it's actually a game. They think it is a typical language lesson. Students are already separated into groups, as they work that way during the whole school year. The story of Archimedes' is about a 4th Grader that loses enthusiasm of learning in school and his teacher accuses him of not trying at all and always being day dreaming. So his parents decide to send him spend some time with his grandfather. His grandfather is a very strict man with a love for knowledge. During his stay at his grandpa's Archimedes finds out that his grandpa owns a very strange machine. A time machine! Thereafter he begins his journey, but unfortunately he forgets the chest that will allow him to return and gets trapped in space and time. He asks through a message shown in the classroom board help from the students to be set free. The aim of the game is for the students to collect various clues, while travelling in time in groups, in order to unlock a chest. The chest contains the date Archimedes set out for his journey and this is the only clue that will allow him to return.

Figure 1. Group 3 Challenges

IMPLEMENTATION

The duration of the journey is about 50 minutes and in case of difficulty student groups are required to help each other. Every group consists of 4-5 members and is given a miniature suitcase, which contains a riddle, an object, an answer sheet, a map and a tablet. Students form six groups, with each group travelling in a different time and space and are required to deal with different instructional objectives. If students have difficulty in collecting a clue they have the right to access the emergency button, which is located in the center of the classroom. When the buzzer is hit all the groups stop working and the group in trouble chooses which member of each group should convene (the managers, the pacifiers e.t.c.) They also have the right to ask for teacher's help, but only once! Additionally, for every app there is a tutorial video inside the tablet, because students aren't familiar with any of these apps.

Teamwork roles

Manager • Reads the rubrics of the exercises and makes sure everyone understands. • Helps group reach a consensus before anything is written. • Keeps time. • Monitors noise level.	**Pacifier** • Solves disputes inside the members of the group. • Makes decisions by ballot when needed. • Confirms whether the group agrees or disagrees with the classroom.
Facilitator • Summarizes the steps needed to complete the task. • Only one allowed to leave the group. • Acquires and cleans up materials.	**Assessor** • Keeps notes of difficulties the group dealt with. • Makes sure all parts of the task are answered. • Checks if a task is answered properly.

Figure 2. The Cooperative Group Roles table displayed in classroom

Group1 receives a suitcase with an illustrated map, the answering sheet, a riddle, a map with the cities named after Alexander the Great and a tablet. The map with the cities named as "Alexandria" informs the group that they are travelling in the past and particularly in the era of Alexander the Great. The answering sheet asks students to select a name for their team and to delegate the responsibilities of every member (manager, pacifier, facilitator, assessor). The riddle is written backwards, so the students use the classroom mirror to decode the message. The riddle refers to the city of Alexandria in Egypt, which is the most known city named after Alexander the Great. The last challenge involves examining the application 'Planimeter' where students are asked to calculate the distance between Thessaloniki in Greece and Smirni in Turkey through mathematical procedures with decimal numbers. This is the final clue that group 1 has to provide for unlocking the chest.

Figure 3. Group 1 challenges

The second team receives a suitcase with an illustrated map, the answering sheet, a mathematical riddle, a paper spacecraft and a tablet. The paper spacecraft informs the group that they are travelling to another planet. The answering sheet asks students to select a name for their team and to delegate the responsibilities of every member (manager, pacifier, facilitator, assessor). The mathematical problem focuses on the time needed by a spacecraft to travel from Earth to Mars. Students perform actions of round numbers, applying critical thinking, in order to find out the exact month and year that the spacecraft will land on Mars. Subsequently, they examine the application 'Globe Mars' which provides them with an abundance of information about planet Mars in English. Through this App they are required to locate the name of spacecraft that landed on Mars on August 2012, named 'MSL Curiosity'. This is the solution of the problem and the final clue that Group number 2 has to provide for unlocking the chest.

Figure 4. Group 2 challenges

The suitcase of the third group contains an illustrated map, the answering sheet, a tablet, a mathematical riddle, a photo of Acropolis of Athens and a poem. The mathematical problem refers to how many kilos of marble were used by ancient Greeks to build the Erehthio temple, performing actions of fractions. The photo presents all of the temples that are located in the Acropolis and students are asked to locate the place of sacred battle between Athena and Poseidon, according to Greek Mythology. Afterwards, they use the 'Acropolis 3D' app in order to observe the temple of Erehthion and answer how many Kariatides they see. The Kariatides are the names the ancient marble sculptures of young women who were used as columns of a building standing next to the Parthenon on the Acropolis. In the 3D app they will find six. Then, they proceed to read a poem that refers to a Kariatida who's been missing and they will have to write a sentence about what would they say, if they were in her place. The missing Kariatida has been housed in the British Museum since 1801. The phrase is the clue that Group 3 has to deliver to the class.

Group 4 travels back in time to the naval combat of Salamina, where ancient Greeks defeated the Persian fleet. Students are given a riddle, a photo of a sail ship in full sail, the answer sheet and the tablet. Their first task is to put the sentences in the right order so the paragraph will make sense. The paragraph refers specific details about the naval combat and is taken from the 'Salamina' app. After the paragraph is complete they are given instructions to locate the specific paragraph in the App by using the divisibility rules of number 3, which reveals the exact number of page and number of paragraph. Subsequently, they explore the app, which provides them with a 3D presentation of the ancient Greek ship, named the Treiris. Then, students have to find out what the name of the part of the ancient ship shown in the picture they are given is called. The part of the sails is called 'mega istiaio' and it is the clue Group 4 has to deliver to the class.

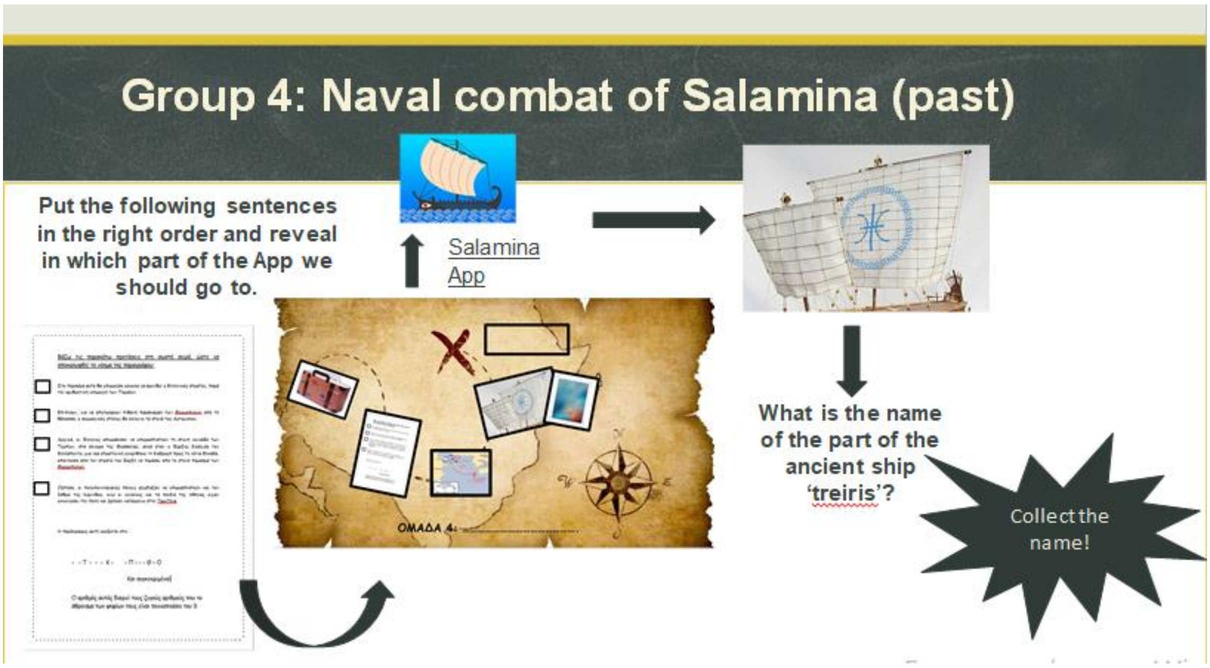

Figure 5. Group 4 challenges

The fifth group of students visits Egypt in the present time. Their suitcase contains a hieroglyph message, two different Egyptian hieroglyphic vocabularies, a picture of a clock and two pictures of flags of foreign countries, the illustrated map, the answering sheet and the tablet. The first challenge of this group is to decode the message written in hieroglyphic language. Students must combine the two different vocabularies in order to reveal the phrase ‘Ancient Egypt’ in English. Their next step is to find out in which countries the two flags refer to, using their own knowledge or by searching information through the internet. The flags belong to Egypt and Canada and they have to use the app ‘City Clocks’ in order to find the time difference between the two countries performing sums in round numbers. This is the final clue for this group.

Figure 6. Group 5 challenges

The last group travels to the cities of future. Their suitcase contains three pictures of buildings of strange architecture, a word puzzle, a cube design, the illustrated map, the answer sheet and the tablet. Students talk about the strange buildings they see in the pictures and make calculated guesses as to where they are travelling. Afterwards, they examine the word puzzle which hides the phrase ‘cities of the future’ among other irrelevant words such as lawyer and cat. When locating the phrase ‘cities of future’ they write in down in their answering sheet. Their next challenge is to create the Rubric cube from scratch. Therefore, after forming the cube, following the directions of the design given, they use information through the internet to learn about the special characteristics of the Rubric cube and paint their own cube the same way. Finally, students explore the app ‘Measure Map Lite’ which shows a picture of our school as it is presented from satellite. Group 6 is asked to calculate the perimeter of the athletic fields of our school performing actions of decimal numbers. The arithmetical number is the final clue for opening the chest.

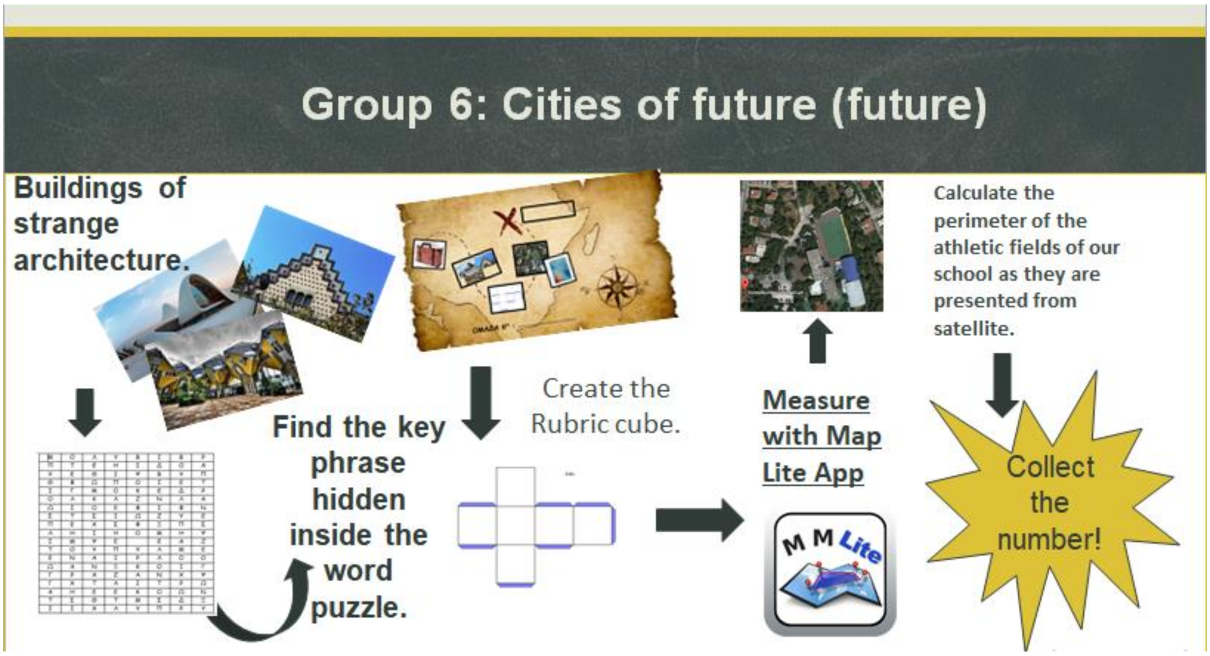

Figure 7. Group 6 challenges

The chest opens only after all six clues have been gathered correctly. At this point the narration of the second part of Archimedes' story follows. Archimedes is finally set free, goes back to school and has the chance to repair his relationship with his teacher and also cooperate with her to make the lesson more interesting with all of new ideas he has obtained during his journey. After that a discussion in the class about what students think keeps them motivated and what they would change follows. Finally, teacher asks students to go to their portfolios were all the transdisciplinary projects are kept and they find a thank you letter from Archimedes for their precious help. In this letter, he also assigns them with a new task, which involves for every group the development of a new riddle, with a form and context of their choosing. The teacher uses these riddles to develop a new A.R.G. and create a never-ending continuum of gamification within the classroom.

Figure 8. The chest, the emergency buzzers and a timer

RESULTS

Based on the class observations students could easily recall prior knowledge, taught through the school year. What is remarkable is the fact that some students with learning difficulties have participated actively. Bear in mind that during the school year they seemed particularly discontent when asked to edit written text. Furthermore, students were asked to apply through playing organizing skills that have developed through the school year and enhance interpersonal relationships management. Feedback from the students was included in the formative amendment of the game. For example, students noticed that allowing student group access the emergency button as many times as a group needed, created a delay in the progress of the game. They proposed having just three opportunities would be more helpful. Furthermore, the first group of 4th Grade students that participated was involved in the further implementation of educational scenario as helpers. Finally, students made remarkable statements about their experience such as ‘I was scared that I might break the iPad, so I was trying the whole time to hold it gently’, ‘The riddles were perfect’, ‘It is only now that I understand why our parents keep telling us that they are working and not playing while using their tablet’.

CONCLUSIONS

Problem solving situations, Internet application, and scaffolding procedures created a unique experience for the students. Students beginning from level ‘Comprehend’ of the reversed pyramid of Bloom’s Taxonomy (Krathwohl, 2002) were led to level ‘Create’, by encouraging students to create their own riddles and to document their own ideas for a new game. Consequently, Alternate Reality Games in the classroom appear to be particularly useful, as they motivate students and, concurrently provide teachers with the opportunity to go beyond evaluation of instructional objectives and focus on skills and competences when students work in an active gaming.

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THE EFECTIVESNESS OF 'LADDERS OF LEARNING' IN CHEMISTRY EDUCATION

Marie-Therese Hauerstein and Helena van Vorst
University Duisburg-Essen, Essen, Germany

School classes are dominated by heterogeneity in terms of differing prior knowledge, interests and cognitive abilities. During lessons, teachers have to deal with this heterogeneity to support individual learning. The concept 'Ladders of Learning' constitutes a teaching method which aims fulfilling these demands. It structures learning processes, divides the learning content into several parts and allows the integration of phases with differentiated instruction. The aim of this study is to analyse the effectiveness of 'Ladders of Learning' in terms of students' cognitive and affective variables. First results of the pilot study reveal satisfying test instrument reliabilities and significant increases in students' learning outcomes.

Keywords: structuring, differentiated instruction, chemistry education

INTRODUCTION AND THEORETICAL FRAMEWORK

Problem Statement

Students are diverse, for example in terms of prior knowledge, cognitive ability and interest. Caring for successful individual learning processes of every single student, it is necessary to address these differences in school lessons (Dixon, Yssel, McConnell & Hardin, 2014). An opportunity to handle this challenge is offered by the concept called 'Ladders of Learning' which structures both the learning process and the learning content. Furthermore, it integrates phases of differentiated instruction. Thus, *Ladders of Learning* combine a high degree of structuring with differentiated instruction.

How *Ladders of Learning* affect students' learning outcome, interest and motivation has not been examined so far. Furthermore, it is not clear to what extent structuring and differentiated instruction interact with each other and which effects result from a combination of both.

Differentiated Instruction

Over the last decades, numerous approaches for handling heterogeneity in the classroom were developed. They can be summarized under headings like individualised instruction (e. g. Fletcher, 1992), adaptive instruction (e. g. Wang, 1980), and differentiated instruction (e. g. Tomlinson, 2003). Most studies focusing on these methods show positive effects on students' learning outcomes. Taking a closer look at these studies, differences in the realised ways of differentiation can be identified. For instance, the use of differentiated learning material and a variation of the learning pace lead to positive effects in terms of students' learning achievement. In a study conducted by Slavin & Karweit (1985) maths classes were divided into a high-ability group (around 60 % of the students) and a low-ability group (40 %). The teacher had to differentiate the material and the learning pace, especially to raise the learning pace for the high-ability students. The material was differentiated by involving 'a high ratio of active instruction to seatwork […], teaching mathematics in the context of meaning, frequent questions and feedback, and management strategies' (Slavin & Karweit, 1985, p. 355). As a result, the students of the intervention group learned significantly more than the students of a control group.

In a study conducted by Kallweit (2014), the use of a self-evaluation sheet in chemistry education showed positive effects in terms of students' learning outcomes. While the treatment group worked on exercises concerning the topic of chemical reactions by using a self-evaluation sheet in a 90-minute chemistry lesson, the control group worked without this sheet but with the same material and in the same time. The study showed that the students of the treatment group benefited from the work with the self-evaluation sheet significantly.

Anus (2014) analysed the effectiveness of an individualised assessment on students' achievement within a learning situation. Her results show significant effects on students' learning gains when they are assigned to exercises individually based on a diagnosis.

However, Gruehn (2000) concludes that differentiated instruction leads to negative effects on students' learning outcome when it is accompanied by a great amount of organizational efforts. As a reason for this, Gruehn assumes students to have potentially less time on task when dealing with this extra effort.

Studies concerning differentiated instruction show that not every student benefits from differentiated instruction in the same way: i. e. high-ability students profit more than low-ability ones (e. g. Kulik & Kulik, 1992, Mavarech & Kramarski, 1997). As low ability students are overstrained by too independent learning settings, they rather benefit from highly structured lessons (Snow, 1989).

Structuring

Structuring in general is one characteristic of high-quality teaching (Kounin, 2006). According to Meyer (2014), general indicators for a well-structured lesson are a plausible subdivision of the learning content and clear-cut lesson phases.

In order to enable successful learning of all students, sequencing of the learning content should take students' learning development into account. Students' understanding and learning progress are described within so-called *learning progressions. Learning progressions* provide 'empirically grounded and testable hypotheses about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with appropriate instruction' (Corcoran, Mosher, & Rogat, 2009, p. 8). They consist of different components: a lower anchor (meaning those abilities students already have when starting the learning sequence), an upper anchor (meaning the knowledge goals to be achieved) and several stages of progress in between (Duschl, Schweingruber, & Shouse, 2007). The concrete stages of progress are assumed in advance and validated afterwards (e. g. Stevens, Delgado, & Krajcik, 2009).

Apart from the sequence of the learning content, the content itself should be presented to the students in a structured way (Helmke, 2014). An opportunity to structure lessons are structuring auxiliaries such as advance organizers, concept maps, or *Ladders of Learning* (Ausubel, 1960; Nesbit, & Adesope, 2006; Meyer, 2014; Müller, Lichtinger, & Girg, 2015). Advance organizers date back to the 1960s and David Ausubel. In his original concept, Ausubel described advance organizers as a textual summary of a new learning content. Furthermore, in a study by Holländer (2010), advance organizers were used as a figural summary. Advance organizers are presented to the students to facilitate the following learning process. They have the characteristic of structuring the learning content, but they do not set the structure of the learning process in advance. In previous studies, advance organizers achieve significant increases in students' learning outcomes (e. g. Ausubel, 1960; Holländer, 2010).

Concept maps are diagrams that node-link different terms, adding a description of the linked terms' relation. Just like advance organizers, concept maps only structure the learning content, without giving any information about the order of the learning phases (Nesbit & Adesope, 2006). Meta-studies by Nesbit and Adesope (2006) and by Horton and coworkers (1993) come to the conclusion that the use of concept maps leads to positive effects on student achievement. Students of different educational levels benefit from concept mapping in the same way.

A structuring auxiliary that sets the sequence of the learning phases in advance, considers students' learning progression and includes phases of differentiated instruction has been put forward in the form of *Ladders of Learning.*

Concept 'Ladders of Learning'

The concept *Ladders of Learning* was developed in India in the 1980s to establish school education in rural areas. It focuses on an increased structuring of school lessons and illustrates it to the students. The *Ladder of Learning* organizes the learning content into several parts, called 'milestones', which are based on each other. Each milestone has an inner process structure which systemises the corresponding school lesson (Müller, Lichtinger & Girg, 2015). For this study, learning material for the chemical topic 'Bohr's atomic model' has been developed. The related *Ladder of Learning* contains three milestones (Figure 1) that fit the steps of progress proposed and reviewed in a 'Structure of Matter' *learning progression* by Weber, Emden, & Sumfleth (2016).

Every milestone starts with the introduction of a new learning content. This part is called *Introductory* (Figure 2). Subsequently, students work on exercises to practice the basic knowledge necessary for the lesson (*Basic Exercise*) before they go through a self-evaluation phase to diagnose their individual learning achievement (*Self-Evaluation*). Based on the results, they are assigned to exercises on three different levels of difficulty (*Individualised Exercise*). In order to realise a systematic variation of the levels of difficulty, these exercises have been constructed following the structural competence model for scientific inquiry developed within the project *Evaluation of Standards in Science for Secondary School (ESNaS)* (Köller et al., 2008). The part *Individualised Exercise* aims at reinforcing or transferring the new learning content and is conducted in the form of an individualised practice phase. Each milestone is completed by a short content knowledge test and a PowerPoint presentation repeating the learning content of the current milestone (*Final Evaluation*).

The *Ladder of Learning*-related learning material used for this study was developed within the North Rhine-Westphalian project *Ganz In* in cooperation with several teachers from upper secondary schools. Around ten 90-minute chemistry lessons are needed to implement the material in school. The material contains worksheets with exercises that require to be completed in different cooperative learning arrangements. For instance, they include educational games designed to develop a conception of atomic models or to improve the jargon of chemistry. Furthermore, students have to develop models, for example for the periodic table, and compare them.

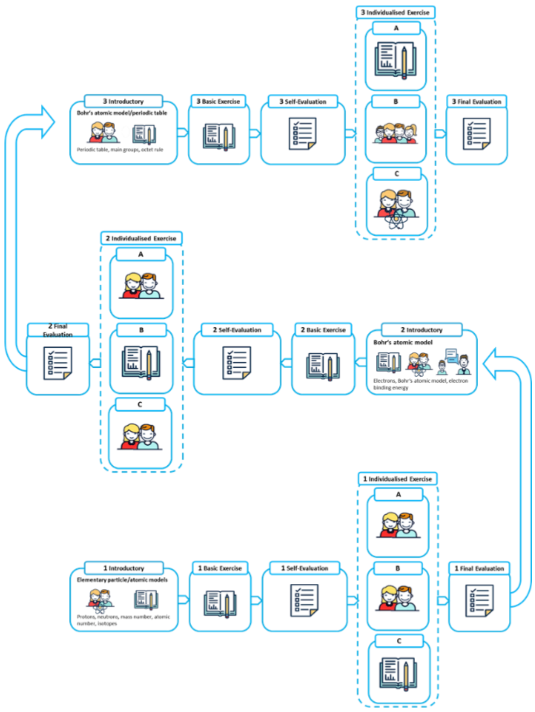

Figure 1. The developed 'Ladder of Learning'

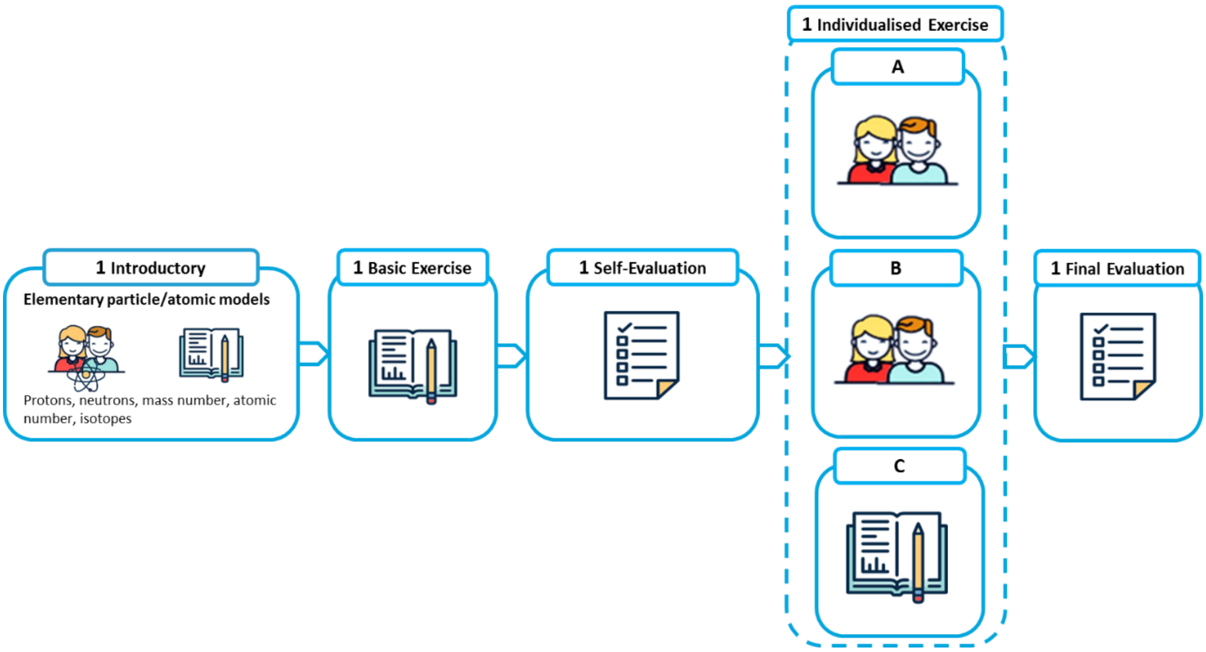

Figure 2. First milestone of the developed 'Ladder of Learning'

METHOD AND DESIGN

Research Questions

This study focuses on the following research questions:

RQ1: To what extent does **structuring** by *Ladders of Learning* have an effect on students' learning outcome, interest and motivation?

RQ2: To what extent does **differentiated instruction** within the *Ladder of Learning* enhance students' learning outcome, interest and motivation?

RQ3: To what extent does the combination of both treatments, **structuring** and **differentiated instruction**, have an effect on students' learning outcome, interest and motivation?

Study Design

To answer these research questions, an intervention-control group study in a 2x2-design is conducted. As can be seen in Figure 3, three treatment groups and one control group are realized within the design: intervention group A receives both treatments, structuring and differentiated instruction, while group B and group C receive only one of these two treatments. Group D serves as a control group and receives neither structuring nor differentiated instruction.

A Structuring Differentiated Instruction	**B** Structuring No Differentiated Instruction
C No Structuring Differentiated Instruction	**D** No Structuring No Differentiated Instruction

Figure 3. 2x2-design of the study

This means group A and group B work with the developed learning material of the *Ladder of Learning* (Table 1). Instead of using the exercises with the three different levels of difficulty in the element of *Individualised Exercise*, all students of Group B work with the material that has the average level of difficulty. Group C works with material prepared by the teacher and supplemented by learning tasks of the *Ladder of Learning* for realizing the intended differentiation. In group D, the teacher uses his or her own material for this unit.

Table 1. Treatments of the four groups

Group	**Treatment**	
	Structuring	**Differentiated Instruction?**
A	by *Ladder of Learning*	Yes (*Ladder of Learning*-related material)
B	by *Ladder of Learning*	No (all students work on the *Ladder of Learning*-related exercises with the average level of difficulty)
C	by teacher	Yes (*Ladder of Learning*-related material)
D	by teacher	No

Participants

In winter 2016/2017 a pilot study with two groups of the study design was conducted in order to test the quality of the developed learning material for the *Ladder of Learning* (group A) and to examine the feasibility of group C. The developed learning material and the material for the differentiated instruction have been implemented in one class of 8th grade each from the same upper secondary school in Germany. Both classes were taught by the same teacher and had no significant differences in terms of the tested variables at the pre-test. The participating students (n_A = 24; 54.2 % female; n_C = 20; 60 % female) were between 13 and 14 years old on average.

Test Instruments

In order to investigate students' learning achievement before and after the intervention, a topic-specific multiple-choice questionnaire in a single-select format has been developed and tested within the pilot study. Additionally, students' self-concept, their motivation and individual interest in chemistry at school as well as their interest in the relevant topic 'Bohr's atomic model' have been surveyed as control variables with the help of a Likert-scaled questionnaire, adopted from Fechner (2009) and van Vorst (2013). For illuminating the development of students' content knowledge and situational interest during the intervention, the relevant variables have been surveyed after every milestone with the help of a questionnaire adopted from Fechner (2009) and Holländer (2010). As can be seen in Table 2, the reliabilities of the used items are good to excellent ($.86 \leq \alpha \leq .91$), except for the pre-test scale for content knowledge. The poor reliability of the pre-test scale can be attributed to the fact that the tested items refer to the content of 'Bohr's Atomic model' that students learn during the intervention, hence the items are too difficult for them at the first point of measurement. The purpose of this questionnaire is to detect students' prior knowledge. With regard to their score in items that correspond to the probability of guessing (Table 3), it can be said that they nearly have no prior knowledge in terms of the current topic.

Table 2. Reliability of the test items

	Pre	Post
Content knowledge (45 items)	α = .55	α = .90
Individual interest & intrinsic motivation (10 items)	α = .86	α = .91
Self-concept (7 items)	α = .86	α = .87

FIRST RESULTS AND CONCLUSIONS

Between the two groups A and C, only the kind of structuring is varied. While the students of group A work with the developed learning material of the *Ladder of Learning*, the students of group C work with the material prepared by their teacher and supplemented with the *Ladder of Learning*-related material for the intended differentiation. Hence, the differentiated instruction was systemized for both groups.

Content knowledge

The results show significant knowledge gains for both groups (A: $t(23) = 9.896$, $p < .001$; C: $t(17) = 9.488$, $p < .001$) with large effect sizes (A: $d = 2.29$; C: $d = 1.69$). In the content knowledge test, 45 points were the maximum. The reached points of the two groups are listed in Table 3 and Figure 4 for both points of measurement. Between the two groups, there are no significant differences in terms of knowledge gains.

Table 3. Results of the content knowledge test

Group	M_{pre}	M_{post}
A	12.92 points (SD = 4.19)	27.08 points (SD = 7.66)
C	14.00 points (SD = 4.52)	27.25 points (SD = 10.12)

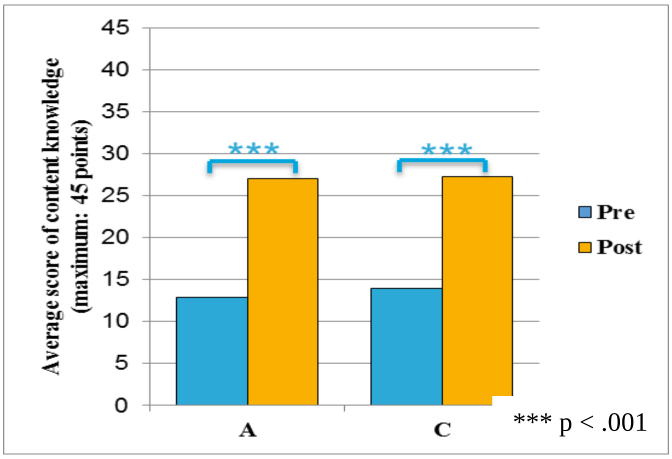

Figure 4. Knowledge gains of group A and group C

Self-concept

Further results in terms of students' self-concepts are summarized in Table 4 and Figure 5. The self-concept questionnaire was Likert-scaled from 1 (= very bad) to 4 (= very good). As can be seen, there are significant gains in students' self-concept of group A ($t(22) = 2.631$, $p = .015$) with a small effect size ($d = .42$). In group C there is no significant change in students' self-concept ($t(14) = 1.980$, $p = .068$, $d = .25$). Group A differs from group C in the kind of structuring. As the lessons of group A were structured by the *Ladders of Learning* related material, the lessons of group C were structured by the teacher. The results indicate a benefit of structuring by *Ladders of Learning*. Due to the small sample size, the results cannot be generalized before the results of the main study are available.

Table 4. Results of the self-concept questionnaire

Group	M_{pre}	M_{post}
A	2.35 points (SD = .45)	2.55 points (SD = .50)
C	2.52 points (SD = .63)	2.68 points (SD = .63)

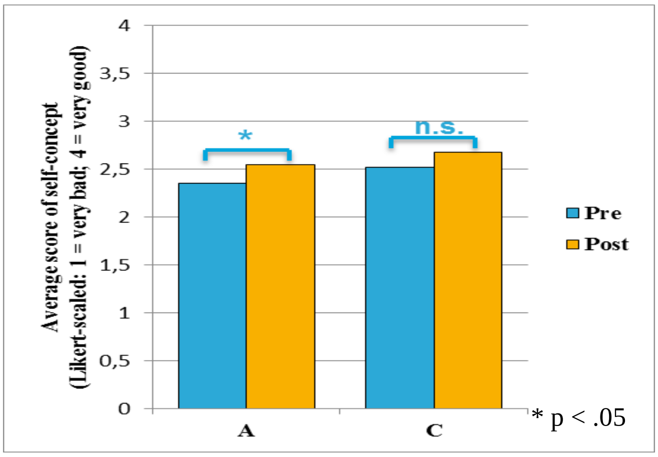

Figure 5. Self-concept of group A and C

Individual Interest and Intrinsic Motivation

Figure 6 and Table 5 summarizes the results for students' intrinsic motivation and individual interest in chemistry. The related questionnaire was Likert-scaled from 1 (= absolutely wrong) to 4 (= absolutely right). In both groups, there is no significant change from the pre-test to the post-test (A: $t(23) = .785$, $p = .441$, $d = .12$; C: $t(18) = .128$, $p = .899$, $d = -.02$). The tested variable seems to be too stable to be affected by this intervention.

Table 5. Results of the individual interest and intrinsic motivation questionnaire

Group	M_{pre}	M_{post}
A	2.54 points (SD = .57)	2.61 points (SD = .61)
C	2.67 points (SD = .66)	2.66 points (SD = .52)

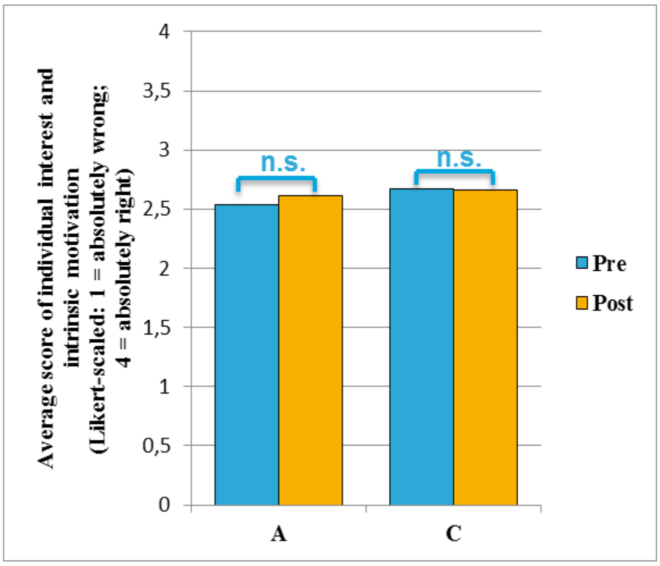

Figure 6. Individual interest and intrinsic motivation of group A and C

Effects for different ability groups

As described above, the students of both groups were assigned to three different ability groups for the phase of differentiated instruction. This assignment was based on students' results in their self-evaluation sheet and therefore oriented on their content knowledge. That is why in the following, the effects on students' content knowledge are described for different ability groups.

To see whether there are any differences in terms of content knowledge increase between low-, middle- and high-ability students within one group (intervention or control group), the sample was divided into different ability groups based on the students' last chemistry grade. The German grade system distinguishes between six different grades, with 1 being the best grade. Figure 7 and Table 6 summarize the results. Because of the fact that the differences between the groups are not statistically significant for the first point of measurement, the content knowledge gains are reported from a descriptive perspective.

The low-ability students of group A have an average knowledge gain of 14.17 points. The low-ability students of group C reach 13.00 points more at the second point of measurement than at the first point of measurement. The difference between the two groups measures 1.17 points. Hence, students who learn with the material of the *Ladder of Learning* have a content knowledge gain that is in average 1.17 points larger than the one of the students learning without this material.

The average total score of the middle-ability students of group A have an average content knowledge gain of 13.7 points. The middle-ability students of group C gain 13.5 points in average. The difference of the two groups measures 0.23 points. Hence, there is nearly no difference between the two groups.

Looking at the high-ability students of group A, their average content knowledge gain is 15.57 points. The high-ability students of group C gain in average 13.13 points. Comparing the two high-ability groups, there is a difference of 2.44 points for the benefit of the students of group A.

Table 6. Results of the content knowledge test for different ability groups

Group	***Low-ability***				***Middle-ability***				***High-ability***			
	M_{pre}	SD_{pre}	M_{post}	SD_{post}	M_{pre}	SD_{pre}	M_{post}	SD_{post}	M_{pre}	SD_{pre}	M_{post}	SD_{post}
A	11.00 points	4.15	25.17 points	7.94	13.91 points	4.66	27.18 points	7.40	13.00 points	3.37	28.57 points	8.64
C	12.00 points	1.41	25.00 points	10.99	14.00 points	5.35	27.50 points	11.72	15.00 points	4.75	28.13 points	9.22

Because of the fact that every ability group has knowledge gains, it can be concluded that the material is appropriate for each level of ability. Compared to the students of group C, especially the low-ability and the high-ability students of group A seem to profit from the *Ladder of Learning*-related material. Both groups work with the individualised exercises, hence, the small descriptive benefit of the group A students could come from the structure provided by the developed *Ladder of Learning*.

Implementation of the material

In the conducted study, the self-evaluation questionnaire assigned too many students to the highest level of difficulty. The reason for this seems to be the length of the questionnaire which is clearly too short. The students only have two or three abilities in which to self-evaluate. In case the students consider themselves as competent in terms of these items, they are assigned to the exercise with the highest level of difficulty. To distribute the students between the different levels of difficulty more evenly, the self-evaluation questionnaire has been revised as to include more different abilities. Besides this, all abilities are formulated more like short tasks to avoid too abstract phraseologies.

In addition to that the teacher's content structure in the lessons of group C was very similar to the one of group A. It might well be that the teacher has been influenced by the structure of the *Ladder of Learning* material.

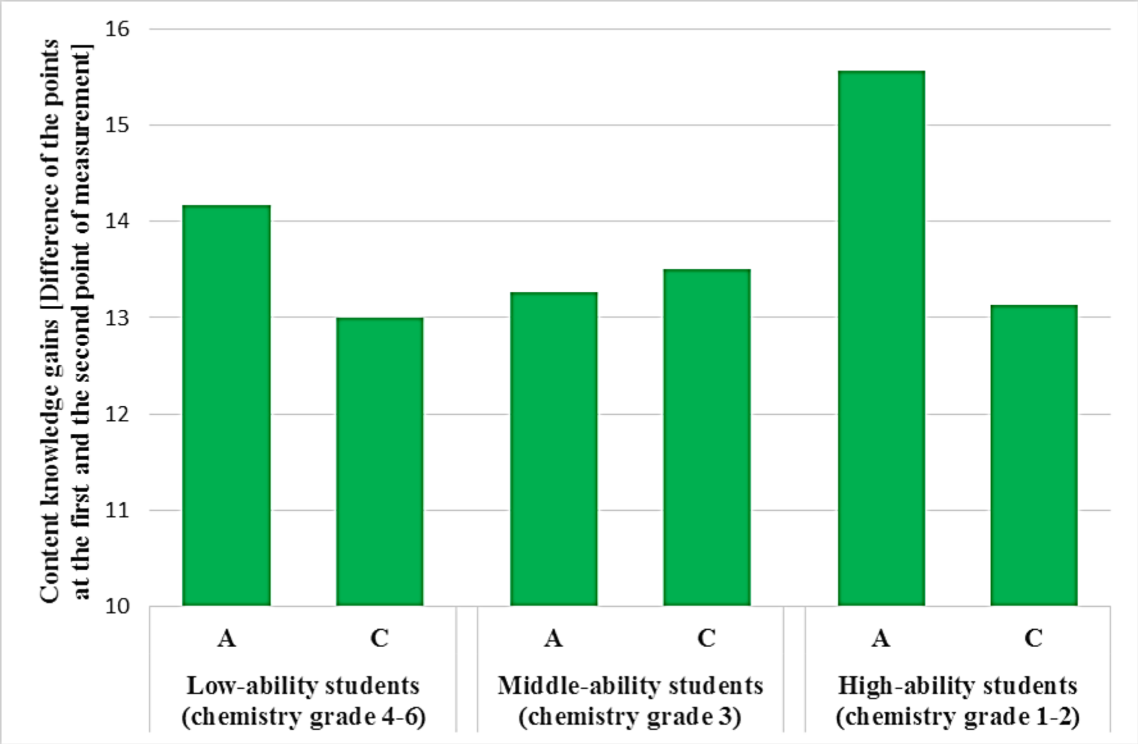

Figure 7. Knowledge gains of the ability groups of group A and C

CONCLUSIONS

The use of the developed learning material for the *Ladder of Learning* leads to significant knowledge gains. Nevertheless, the material will be partly revised for the main study. Especially the self-evaluation sheet will be re-examined and extended. The reliabilities of the test instruments are satisfying.

To generate further information about the influence of differentiated instruction on the tested variables and to examine interaction effects of structuring by *Ladders of Learning* and differentiated instruction, the main study is conducted in winter 2017. The sample of the main study is expected to consist of about 500 students from the 8^{th} grade from 12 upper secondary schools in Germany.

Furthermore, in the main study, measures will be taken to minimize influences of *Ladder of Learning*-related material (used in groups A and B) on the structure of the lessons without this material planned by teachers (groups C and D): From each school, two classes taught by the same teacher will be assigned to either groups A and B or groups C and D (Figure 3). Thus, the combination of groups with and without the *Ladder of Learning* structure is avoided.

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A MODEL-BASED GENERAL RELATIVITY COURSE FOR PHYSICS TEACHERS

Ute Kraus, Corvin Zahn, Thomas Reiber and Stephan Preiß
Hildesheim University, Hildesheim, Germany

The general theory of relativity is one of the foundations of today's physical worldview and should therefore be part of the education of physics teachers and also of the school curricula. We present a general relativity course for pre-service physics teachers that is model-based and conceptual rather than mathematical. The course is comparatively short, uses only elementary mathematics, and has a focus on the basic concepts and on the physical phenomena. We also present an evaluation of the course based on written exam papers of students at Hildesheim University over several years of teaching the course. The teaching strategy relies on the fact that general relativity is a geometric theory. Graphic constructions are used to study the properties of curved spacetime. This is made possible by the use of sector models (Zahn & Kraus, 2014) as tools to represent curved spaces and spacetime true to scale. The evaluation is focussed on students' ability to construct and use sector models.

Keywords: general relativity, astrophysics, teacher education

INTRODUCTION

The general theory of relativity is one of the foundations of today's physical world view. Its importance lies both in the fundamental concepts, forming the physical notions of space, time, and gravity, and in the relativistic phenomena that are of major importance in cosmology and astrophysics.

However, in the university education of pre-service physics teachers in Germany, a course in general relativity usually is not part of the curriculum. The existing courses in general relativity are aimed at future theoretical physicists. They involve learning an extensive mathematical apparatus and therefore require a substantial amount of time. In the German teacher education, where future teachers study two subjects plus education science, such a comprehensive general relativity course does not fit into the time available for studying physics. Also, the standard course is an approach that cannot be transferred to school since it involves mathematical concepts that are way beyond the elementary mathematics taught in school.

Teacher education requires a general relativity course sui generis: a short course, with a focus on conceptual understanding rather than on the mathematical formalism, and with an emphasis on the physical phenomena and their astrophysical significance. In this contribution we describe a general relativity course along these lines. It has been developed and evaluated in the physics teacher education at Hildesheim university.

TEACHING STRATEGY

John Wheeler summarized the basic ideas of general relativity stating that "Spacetime tells matter how to move. Matter tells spacetime how to curve." (Wheeler, 1990). Thus, the basic concept is curved spacetime and its properties, notably its geodesics (being the paths of freely falling particles and of photons) and its curvature (being related to the distribution of matter).

It is apparent that general relativity describes gravity with geometric concepts. These are familiar in the special case of Euclidean geometry, where geodesics are straight lines and the curvature is zero. When questions are geometric in nature we can often use intuitive geometric insight or we can find solutions by graphic construction.

Our teaching strategy for a short and conceptual general relativity course is to use graphic construction and by doing so to aim at developing geometric insight for non-Euclidean geometries. Graphic construction in curved spaces and spacetimes is made possible by using a novel tool developed for this purpose. Sector models (Zahn & Kraus, 2014) are physical models of curved spaces and spacetimes. They are constructed true to scale so that the geometric properties that are inferred from the models are quantitatively correct.

The sector models are two-dimensional (e.g. the symmetry plane of a spherical star), three-dimensional (e.g. the curved three-dimensional space around a black hole), or 1+1-dimensional (i.e. a spacetime with two spatial dimensions suppressed, like in the Minkowski diagrams of special relativity). They permit to construct geodesics with pencil and ruler and to determine curvature components by the measurement of deficit angles with a protractor (Zahn & Kraus, 2014; Kraus & Zahn, 2016).

COURSE DESCRIPTION

The general relativity course at Hildesheim University is taught within a seven week period with a weekly lecture (90 minutes) and a weekly tutorial class (90 minutes). Homework problems are set each week and students are required to work on them on their own prior to discussing results in the tutorial. The course has been developed over several years in cycles of teaching, evaluation, and redesign. It is part of the physics curriculum of pre-service physics teachers.

LECTURE

This sections gives a summary of the lecture (see Table 1 for an overview) with a comparison between the model-based course and standard introductory courses.

Part I Introduction

The introductory chapters of the model-based course are similar to those of many introductory texts on general relativity (e.g. Hartle, 2003; Natário, 2011).

The course starts with the principle of equivalence. The well-known thought experiments about a laboratory system in free fall are used to show that light deflection and gravitational red shift are consequences of the equivalence principle. This section then goes on to give a description of the basic ideas of the general theory of relativity: Gravity is geometry, and a curved four-dimensional spacetime gives rise to the gravitational phenomena.

Next, basic geometric concepts are introduced by studying curved surfaces, in particular the sphere (Figure 1). Curvature is described in a qualitative way that permits to distinguish between positive, negative, and null curvature by inspection (Rindler, 2001). The criterion for positive curvature, for instance, states that a small piece of the surface, when flattened in the plane, must tear. Geodesics are defined as lines that are locally straight, i. e. lines that locally keep their direction. Using a globe as a physical model, geodesics are studied on the sphere. Geodesics are then used to highlight the non-Euclidean geometry of the sphere (e. g. by showing that two initially parallel geodesics converge, Figure 1). The concepts of coordinates and metric are introduced using the Euclidean plane in polar coordinates and the sphere in spherical coordinates as examples.

Table 1. Outline of the model-based lecture on general relativity as described in the text.

Table of contents	*Keywords*
I Introduction	*the equivalence principle, gravity as geometry, plane and curved surfaces: coordinates, metric, curvature, geodesics*
II The geometry of curved surfaces	*sector models of curved surfaces: how to study curvature and geodesics with a sector model*
III The Schwarzschild spacetime	
III.1. The equatorial plane	*light deflection, gravitational lenses*
III.2. The spacetime of a radial ray	*redshift, vertical free fall, comparison with Newtonian gravity*
III.3. Space around a black hole	*curvature in three dimensions, the field equations*
IV Cosmology	*Introduction to observational cosmology, cosmological redshift*

Figure 1. Introduction to non-Euclidean geometry: The geodesics of the sphere are the great circles, initially parallel geodesics converge.

Part II The geometry of curved surfaces

This part of the course introduces the tools for studying a curved surface specified by its metric. From the given metric, the geodesics and the curvature are to be determined. At this point, the course deviates from the traditional approach and takes a new path. It does not introduce the geodesic equation and the curvature tensor like the mathematically minded courses (e. g. Hartle, 2003). Instead, sector models are introduced. Again using the sphere as an example, its sector model is constructed and is then used to determine geodesics and curvature. Figures 2 and 3 give a summary of the procedure (for details see Zahn & Kraus 2014; Kraus & Zahn, 2016): The sphere is subdivided into small elements of area (Figure 2a, b). Then, using the metric, the lengths of the edges of all quadrangles are calculated. Finally, quadrangles with the same edge lengths (and the same symmetry properties) are constructed in the Euclidean plane (Figure 2c). These are the sectors that make up the sector model. Each sector can be thought of as a nearly true-to-scale map of the corresponding part of the sphere. Figure 3 illustrates the use of the model: Geodesics are constructed as locally straight lines with pencil and ruler (Figure 3a). In the case of initially parallel geodesics, e. g. this reproduces the fact that two initially parallel geodesics on the sphere converge (Figure 3b, Figure 1). The geodesics obtained with this graphic method are approximate solutions of the geodesic equation with an accuracy depending on the resolution of the sector model. Curvature is determined by applying the criteria for positive, negative, and null curvature on the level of the discrete model. Figure 3c shows "tearing" of a small part of the surface made up of four sectors sharing the central vertex, thus indicating the positive curvature of the sphere.

Figure 2. Construction of the sector model of a sphere. The sphere is subdivided into small quadrangles defined by their vertices (a, b). Quadrangles with the same edge lengths are constructed in the Euclidean plane (c); these are the sectors that make up the sector model.

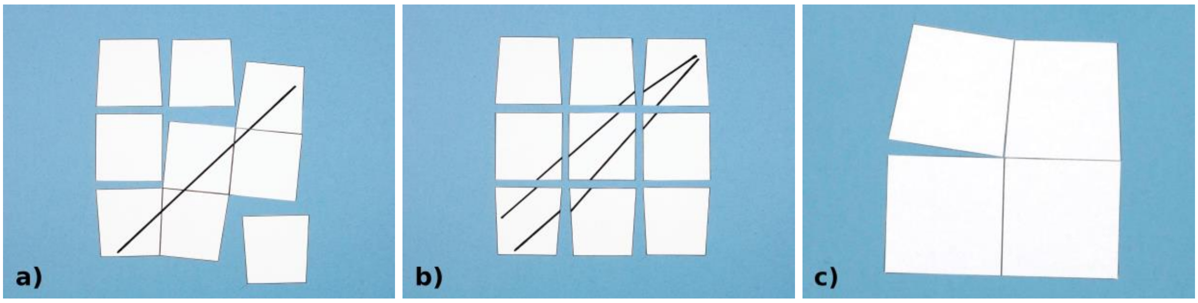

Figure 3. Use of the sector model of a sphere. Geodesics are constructed as locally straight lines (a), reproducing the properties of geodesics on the sphere (b, see Figure 1). The criteria for the qualitative determination of curvature are applied to the discrete model, showing the positive curvature of the sphere (c).

Part III The Schwarzschild spacetime

The Schwarzschild spacetime, describing the exterior of a spherical star or a black hole, is arguably the most frequently and extensively treated example in textbooks on general relativity. This course is no exception and is strongly focussed on the gravitational phenomena occurring close to a black hole. Besides its importance, this example has the advantage that gravitational effects are large in the vicinity of a black hole and are therefore clearly visible in the sector models.

The spacetime in the exterior region of a black hole is studied by applying the methods developed in part II to subspaces of dimension two and three of the Schwarzschild spacetime. In the process, the methods are extended from two spatial dimensions to three spatial dimensions and to a spacetime with one spatial and one temporal dimension.

The equatorial plane

The objective in studying the equatorial plane of a black hole is to convey a conceptual understanding of light deflection. This understanding is actually reached by way of an analogy, because this section is limited to geodesics in space (as opposed to photon worldlines in spacetime).

Due to the spherical symmetry of the Schwarzschild spacetime any geodesic lies completely within a plane of mirror symmetry, in the following called an equatorial plane.

A sector model of the equatorial plane is computed based on its metric and geodesics are drawn across the sector model. This proceeds exactly as described in part II, substituting the Schwarzschild metric of the equatorial plane for the metric of the sphere (Kraus & Zahn, 2016).

The main result is the observation that a geodesic is, on the one hand, a straight line by construction (Figure 3), i. e. a line that at no point exhibits bends or kinks. On the other hand, when a geodesic is constructed that passes close to a black hole, the direction "far behind" the black hole turns out to be different from the direction "far ahead". Transferred to light rays: A light ray is everywhere straight. When it passes through a region of curved spacetime, the asymptotic directions before and after are different. The graphic construction visualizes that these two observations are in accord. Further constructions on the sector model are used to study more details, e. g. the formation of double images. The results are the basis for a discussion of gravitational lenses using both astronomical observations and computer visualizations.

<u>The spacetime of a radial ray</u>

By suppressing two spatial dimensions (as in the Minkowski diagrams of special relativity) and considering the spacetime of a radial ray, the worldlines of light and particles in radial motion can be constructed (Zahn & Kraus, 2018a, 2018b). The goal of this section is to infer gravitational redshift from the Schwarzschild metric and to study vertical free fall in comparison with the Newtonian description.

In this section, a spacetime sector model is computed. The procedure is similar to that described in part II, but must take into account that the metric is not positive definite, so that negative intervals are computed for timelike sector edges (or for spacelike edges, depending on the choice of signature).

To show gravitational redshift, two radial null geodesics are constructed on the sector model. They represent light signals that are emitted at the same radial distance from the black hole, one a short time after the other. The construction shows that signals moving outwards arrive at a larger radial distance with an increased time delay. When the two geodesics are interpreted as the worldlines of wave crests, this translates into an increase in period, i. e. a redshift.

Vertical free fall is studied by constructing timelike geodesics corresponding to objects released at some distance from the black hole with some initial velocity. When the object is thrown upwards, e. g., intuition tells us that it will reach a maximum height and then fall back down (provided it starts with less than the escape velocity). In the general relativistic description, the path of the object is a geodesic, i. e. a straight line. The construction shows nicely that these two descriptions are perfectly in accord.

The construction of geodesics is similar to the spatial case shown in Figure 3a. There is an additional requirement, though, because spacetime sectors must be submitted to Lorentz transformations in order to continue geodesics across the borders between neighboring sectors (Zahn & Kraus, 2014).

Space around a black hole

The focus of this section is the study of a three-dimensional curved space and its curvature properties. Its goal is a qualitative understanding of curvature in three dimensions and, based on this, of the field equations.

This section makes use of a three-dimensional sector model that represents the space around a black hole. To this end, the methods described in Part II are extended from two to three dimensions: The space is subdivided into blocks (corresponding to the elements of area in Figure 2b). In case of the black hole sector model the blocks are chosen to be frustums. To test for curvature, sectors are assembled around a common edge (corresponding to being assembled around a common vertex as in Figure 3c).

The test for curvature by means of the three-dimensional black hole sector model shows that curvature must be described not by a single quantity but by three components (Zahn & Kraus, 2014). This understanding paves the way for a qualitative description of the field equations, linking curvature to matter content (Kraus & Zahn, 2018). For the purpose of illustrating the field equations, a simple neutron star model as an example for a non-vacuum spacetime is also studied via its sector model. The neutron star sector model and its use in teaching general relativity will be presented elsewhere.

Part IV Cosmology

The course includes a section on observational cosmology that is similar to the treatment in other introductory texts. Cosmological redshift in the Friedman-Robertson-Walker cosmological model is then studied in more detail. To this end, a sector model is computed for the cosmological spacetime, suppressing two spatial dimensions, and redshift is demonstrated by constructing geodesics. The construction and the handling of the sector model closely correspond to the procedure described in section 'The spacetime of a radial ray'.

PROBLEMS AND TUTORIALS

As described above the lectures are accompanied by homework problems and tutorials. The questions regarding the parts of the course that are presented in the standard way are similar to problems found in standard introductory texts.

Here we will describe the problems that are solved with the sector model approach. They include the construction of additional sector models, both for curved surfaces (e. g. the torus) and for two-dimensional subspaces of curved spacetimes (e. g. the equatorial plane for a simple neutron star model). They also include problems that require handling sector models to study geodesics or curvature. These models are partly constructed by the students on their own (see above) and partly provided as work sheets (in particular spacetime models including Lorentz transformed sectors).

We give two examples of problems that students can work out based on this course by using sector models as tools:

- Consider a spacetime with metric $ds^2 = -c^2dt^2 + (t/14\,T_0)^2dx^2$. Two observers with world lines $x = const$ exchange light signals. Will they observe a redshift?
- The metric of the equatorial plane of a Morris-Thorne wormhole is given by $ds^2 = dl^2 + (b^2 + l^2)d\varphi^2$, where $-\infty < l < \infty$ and $0 \leq \varphi \leq 2\pi$. Two long, straight rigid rods are pushed radially into the wormhole with an angle of 90 degrees between them. Will the rods collide?

LEARNING OBJECTIVES AND ASSESSMENT

Learning objectives can be grouped in three subject areas.

1. Get to know important gravitational phenomena and their significance in astrophysics and cosmology, including light deflection, gravitational lenses, gravitational (cosmological) redshift.
2. Develop understanding for the basic geometric concepts used in general relativity, including non-Euclidean geometry, curvature, geodesics, and metric.
3. Acquire a set of tools to study the physical properties of a (two- or three-dimensional subspace of a) spacetime. This includes the construction of sector models (in two spatial dimensions and in one spatial/one temporal dimension) for a given metric. It also includes the use of sector models for constructing geodesics and for a qualitative determination of curvature (in two and in three dimensions).

The course ends with a written exam with questions of the same type as in the homework problems, addressing objectives of the three subject areas with emphasis on the third. The course is followed in a subsequent semester by a seminar on teaching modern physics in school. Students who completed the course described above then hold workshops on special or general relativity for secondary school students (aged 16 to 19), including among other topics the model-based approach to explain light deflection. Their contributions in this seminar reflect their learning outcomes in subject areas one and two.

In the following section, we present an evaluation of the learning outcomes in subject area three by a combined analysis of the relevant questions in the written exams over several years of teaching this course.

EVALUATION

Participants

The course described above was evaluated using written exams. It was held in the years 2009-2017 with groups of six to thirteen students, resulting in 85 participating students in total. The students were prospective physics teachers in the fourth or fifth semester of their Bachelor studies.

Method

The exams included several complex tasks that led from the construction of a sector model to the determination of the curvature. In some cases, geodesics had to be constructed on a sector model. To quantify the students' understanding of the relativistic concepts taught in the course, we re-evaluated the written exams. For that matter, 22 items in total were developed, which were then rated with a scale ranging from 0 to 4 points. In this scale, 4 points were rated if the task was completely fulfilled. If minor errors, like computational inaccuracies, occurred, a rating of 3 points was made. 2 points were achieved if the answer was partially correct. A rating of 1 point has been made in cases were an answer contained an important feature but major errors and 0 points if the answer was completely wrong. Also included in the rating are students that gave no answer to an item or answers that could not be classified. Out of the 22 items, only 11 were used for this evaluation, because they had the best statistics and contained the relevant aspects for this discussion. The items were assigned to four categories (see Table 2). While some items were exclusive, i. e. a student had to do only one of the tasks (M1 or M2; S1 or S2; GA or GB), other items were summarized (C1 and C2; GA1-3; GB1 and GB2). Here, the rating for a student was obtained by taking the average of the single ratings (rounded off). To test for inter-rater reliability, after the first definition of the items and the scale for rating the answers, 6% of the exam papers were evaluated by five investigators in parallel. The results were discussed and the process led to a minor adjustment in the item definitions.

Table 2. Item definitions and corresponding categories

Category	*Item*
Metric	*M1 – Calculate edge lengths*
	M2 – Calculate distances on the earth surface
Sectors	*S1 – Construct trapezoidal sectors*
	S2 – Sketch trapezoidal sectors
Curvature	*C1 – Phrase curvature criterion*
	C2 – Apply curvature criterion
Geodesics	*GA1 – Draw a geodesic as a straight line in a sector*
	GA2 – Find the starting point of a geodesic in the neighboring sector
	GA3 – Find the direction of a geodesic in the neighboring sector
	GB1 – Draw lighlike geodesics as straight lines under 45° angle
	GB2 – Find the starting point of a lightlike geodesic in the neighboring sector

Results

In the following sections the items are presented together with the corresponding tasks. We also discuss the main sources of errors in the respective task.

The following problem is an example task that was given in one of the exams, probing M1 and S2: The metric

$$ds^2 = [1 - (by)^2]^2 dx^2 + dy^2 \quad (1)$$

with $b = 0.1$ was given on the region $0 \leq x \leq 10, -5 \leq y \leq 5$. The region had to be subdivided into sectors with coordinate length 5 both in x- and y-direction. Then, the edge lengths of the sectors had to be computed and the sectors constructed in the shape of symmetric trapezoids. The items concerning the subdivision of the region and the use of symmetries of the metric will not be discussed here. With this task, the students could show their conceptual understanding of the metric by using it for length calculations (M1). The maximum mathematical complexity of this kind of task was an integration of an elementary function. Overall 88% of the students got a rating of 3 or 4 (see Figure 4, category “Metric”). Here, the reductions in the ratings mainly result from errors in the computation.

The task also showed the students’ ability to construct a sector model. The knowledge of the lengths of the four edges (computed using the metric) is in general not sufficient for the unique construction of a sector. The shape of the sectors is usually a trapezoid which is symmetrical with respect to its central axis (e. g. Figure 2c). This symmetry was always mentioned as additional information. The category “Sectors” could be completely fulfilled by 51% of our students (see Figure 4, cat. “Sectors”). In this case, many errors arose because the imposed symmetry was used incorrectly. In Figure 5, a correct answer to this task is displayed. It corresponds to the metric (1).

The following part of this investigation is focussed on the application of sector models. A main feature of the 2D spatial sector models is that the curvature at a certain vertex can easily be verified to be positive, negative, or null (e. g. Figure 3c). In the exams, the students had the task to apply the criteria for the determination of the curvature at a vertex in a given sector model, either in the constructed sector model from the previous task or in a model that was provided. In our study, firstly, we investigated if the students were able to phrase the curvature criterion themselves (C1) and secondly, if they were able to apply the criterion correctly (C2). The ratings of these two items were averaged and are displayed in the “Curvature”-bar in Figure 4. Here, it is shown that 60 of 85 students (71%) could achieve a rating of 3 or 4 in this category.

Another important application of sector models is the construction of geodesics. In the exams, students had to construct geodesics across a sector model. To do this, geodesics have to be continued from one sector to its neighbor (Figure 3a). There are three important items that are needed to correctly do this construction. At first, a geodesic in a single sector is a straight line (GA1), as we have shown above (see Figure 3a). Secondly, when a geodesic hits the edge of a sector, it starts at the same point on the common edge of the neighboring sector (GA2). And lastly, the geodesic keeps the direction (angle) with respect to the edge (GA3). Similar items can also be applied for the construction of lightlike geodesics on a 1+1D (space and time) sector model. The peculiarity about light rays in these models is that they always have a 45° angle to the space and time axis (GB). In this analysis both versions have been tested. The typical task in this category is to start with two parallel geodesics in one sector and continue both to the other end of the sector model. The construction needed to be done either on a given model or the students had to use the model they created in a previous task. In the latter case, problems arose if the construction of the model was incorrect. Again, the ratings for the above-mentioned items have been averaged. The result obtained here is that 58% of the students have completely fulfilled the task to construct geodesics in a sector model (see Figure 4, category “Geodesics”). The fact that the geodesic is to be continued with the correct angle was a main error source in this task.

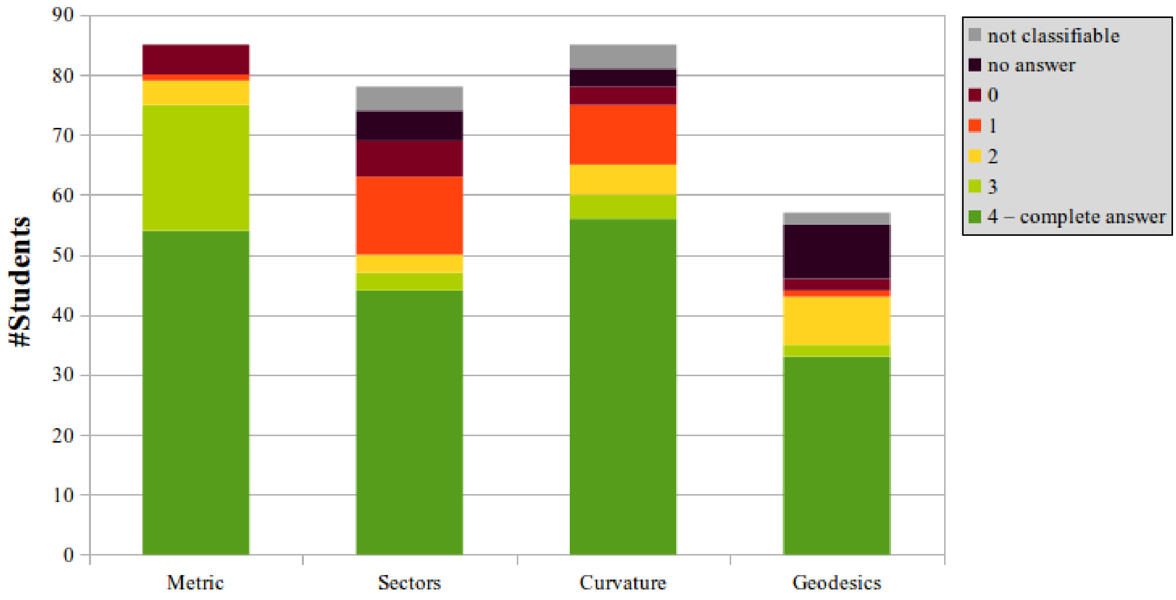

Figure 4. Evaluation results. Tasks addressing the categories "Sectors" and "Geodesics" were not contained in every exam.

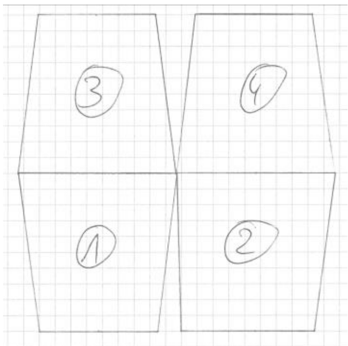

Figure 5. Solution for the construction of a sector model. The sectors are symmetric trapezoids.

DISCUSSION AND OUTLOOK

We have devised and evaluated a general relativity course suitable for physics teacher education. It is a conceptual course with a focus on geometric insight and it is a comparatively short course. The mathematical level is elementary, the metric being the only concept that is beyond standard school knowledge.

The main purpose of the evaluation of this course was to validate if the participants were able to use the tools taught in the course. We assume that with the help of these tools the students can learn the basics of general relativity and improve their conceptual understanding of difficult theoretical building blocks like curved spacetime and the motion of particles on the curved spacetime.

In this analysis, we can show that in the context of our course the concept of the metric is well-known to the students and that the majority of the participants is able to construct a sector model from a given metric of a curved space. We notice that there is a significant difference between the abilities to calculate and to construct a sector model. There is clear evidence that the students in this study are able to deal with the concept of curvature and the results also show that most of the participants of the course have a good understanding of the concept of geodesics. Since these features are important parts in the treatment of general relativity, the course using sector models seems suitable for teaching this subject.

A possible reason for the difficulties that some students had with the tasks discussed above is lack of attendance in the tutorial classes. We have made the observation that active participation in the tutorials is essential for gaining understanding and expertise in handling the sector models. Attendance at tutorial classes is, however, not obligatory and some students attend sporadically or not at all. We expect that this explains a significant part of the incorrent and missing answers. A future evaluation should, therefore, include data on attendance in class.

As we have pointed out, the construction of geodesics on sector models can be used to visualize astrophysical phenomena like light deflection or cosmological redshift. Unfortunately, we have yet too small statistics to conclude if the conceptual understanding of these phenomena can be improved with the tools used in this course.

Besides prospective physics teachers, other students can profit from the model-based approach, e.g. those who study physics as a minor subject. The course can also serve as a supplement to a standard general relativity course and help to strengthen geometric insight.

The course has been developed over several years in cycles of teaching, evaluation, and redesign. Future work will add to the contents of the course (e. g. particles in non-radial orbits, interior region of a black hole) and will also analyse more closely the development of geometric insight through the model-based approach.

Closely related to this work is the question of how to teach general relativity in school that is attracting increasing attention (Natário, 2011; Henriksen et al., 2014; Pitts et al., 2014; Zahn & Kraus, 2014; Kraus & Zahn, 2016). The model-based approach used in the course for physics teachers is also suitable for use in school. A section of the teachers' course has been used in a number of workshops (2 to 4 hours duration) with school classes grades 10 to 13. The approach has been presented at in-service teacher courses both at Hildesheim University (annual "Einstein days") and elsewhere. The development of a course for physics classes in schools is under way.

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RESPONSIVE TEACHING ACTIVATING STUDENTS' EPISTEMOLOGICAL RESOURCES IN SMALL GROUP ARGUMENTATION

Heesoo Ha and Heui-Baik Kim
Seoul National University, Seoul, Republic of Korea

This study aimed to explore how responsive teaching activates students' epistemological resources and affects their epistemological practices in small group argumentation. The participants were a middle school teacher and 53 students in two eighth-grade classes. Students were divided into small groups to develop group arguments. We chose two cases of teacher intervention that showed the teacher's responsive practices when leading the students through epistemologically productive practices. We qualitatively analysed the transcriptions of whole-class recordings and of each group's discourses during the lessons. The analyses showed that the teacher used eliciting questions to understand the students' thinking behind their responses and to support the students in modifying their justifications, leading to epistemologically productive practices. The teacher's responsive moves with conceptual support led the students into deeper discussions and maintained the students' productive practices until they had developed arguments and rebuttals. These findings suggest that teachers need to understand students' thinking by using eliciting questions and support students' epistemologically productive practices. Teachers also need to engage in responsive teaching with conceptual support to help maintain students' epistemologically productive practices. This study contributes to laying the groundwork for teachers' responsive teaching to foster epistemologically productive small group argumentation practices.

Keywords: responsive teaching, epistemological resources, scientific argumentation

RESPONSIVE TEACHING AND STUDENTS' EPISTEMOLOGIES

Responsive teaching is an instructional practice that asks teachers to elicit students' thoughts and respond to them with the purpose of taking in students' ideas in the course of constructing scientific idea (Levin, Hammer, & Coffey, 2009; Pierson, 2008). Kang and Anderson (2015) stated that responsive teachers continuously engage in the cycle of eliciting, attending to, interpreting, and responding to students' thinking throughout the course of instruction at the scale of in-the-moment interactions. Responsive teaching has been explained in various ways, but this study aimed to shed light on responsive teaching grounded in the resource perspective, which asserts that students possess potential thoughts that could be activated and advanced to scientific ideas and practices if they were situated in the proper context (Hammer, Goldberg, & Fargason, 2012). By acknowledging and investigating students' potential, the resource perspective underpins teachers' responsive teaching practices. By applying this resource framework, responsive teaching can be explained as a form of instruction that elicits students' potential resources in the proper context, leading to scientific ideas through a productive process (Hammer *et al.*, 2012).

Students' resources are not confined to the conceptual aspect; they also include an epistemological aspect. To explain the context-dependent nature of students' epistemologies, the resource perspective considers students' cognition regarding the nature of knowledge and learning as constituted by fine-grained and context-sensitive elements (Hammer & Elby, 2002; Louca, Elby, Hammer, & Kagey, 2004). In line with the contention that teachers need to consider the epistemological aspect of students' practices (Duschl, 2008; Osborne, 2010), there has been growing attention to students' activation of diverse epistemological resources in differing contexts (e.g. Berland & Hammer, 2012; Louca *et al.*, 2004).

Although responsive teaching has been proposed for authentic science learning, most of the studies about responsive teaching have focused on responsive practices involving students' conceptual resources, considering students' productive epistemological framing as a larger context (Radoff & Hammer, 2015). Thus, the understanding of how teachers' responsive teaching provides support for students' epistemologically productive practices in science classes still remains limited. Therefore, to expand the understanding of responsive teaching, we explored (1) how responsive teaching practices are carried out and (2) how these practices activated students' epistemological resources and affected their practices in an argumentation activity.

METHOD

The data came from eighth grade mixed-gender classes in a Korean middle school. The research participants were one science teacher (Ms. K) and 53 students from two classes. The students formed seven small groups in each class, with three to four students per group. The teacher majored in biology education and showed a cooperative attitude towards adopting the argumentation activity in her science classes.

During each lesson, the students engaged in argumentation activities that were designed by the researchers. We analysed lessons about eyes and vision. We selected two teacher intervention cases that included the teacher's responsive practices and clearly showed the students' activated resources. In the first case of the teacher's intervention, the students identified the existence of their blind spot through a hands-on activity. They were given a paper containing images of a magician and a mouse. They were asked to continue to focus on the magician while bringing the paper closer and to see what happened to the mouse's image. Then, in the next argumentation activity, a squid eye model and a human eye model were provided, and the students were asked to choose which eye model could explain their experience in the blind spot activity. The models were contrasted in the existence of blind spot, which led to the next argumentation activity about the evolution of eyes in the second case. In the second case of the teacher's intervention, the students constructed claims about which of the two kinds of eyes they would say was more evolved. An argument in the worksheet claimed that the squid eye is more evolved than the human eye. Evidence cards providing scientific concepts about the eye structure of squids and humans were provided to support students' argumentation practices. We transcribed video and audio recordings of the whole-class discourses and of each small group's discourses and conducted semi-structured interviews with the teacher after each lesson. Finally, we qualitatively analysed the videos, transcriptions, and the students' worksheets.

The data analysis passed through three stages. First, we revised the responsive practice framework proposed by Kang and Anderson (2015) so that it would be suitable for explaining responsive practices to the students' epistemological aspects in the argumentation activity. We analysed the teacher's responsive practices based on the revised responsive practice framework, with some inductive modifications to the description of each aspect of responsive practice (Table 1).

Table 5. Teachers' responsiveness to students' epistemological framing in the argumentation activity

Aspects of responsive practice	Description
Eliciting	Asking the students to share the arguments that they constructed or their process of constructing the arguments
Attending	Focusing on a specific part of the students' responses
Interpreting	Inferring students' epistemological framing based on the students' responses that the teacher attended to (e.g., how they think the knowledge claims arise, their stances towards the ideas they encounter, or the type of activity they think they are engaged in)
Responding	Providing support for students to shift to a more productive epistemological framing and engage in more productive epistemological practices

Second, we analysed the students' epistemological practices and their activation of epistemological resources, using a revised epistemological resource framework (Hammer & Elby, 2002) suitable for analysing students' argumentation practices. The categories of the revised framework and the resources in each category are presented in Table 2.

Table 6. Categories of epistemological resources in the argumentation activity

Category	Resources
Resources for understanding the nature and sources of knowledge	Knowledge as a propagated stuff Knowledge as a fabricated stuff
Resources for understanding epistemological forms	Argument with justification Argument with coherent justification based on the data Argument with justification and qualifier
Resources for understanding epistemological stances	Acceptance of an epistemic authority Critical evaluation of justification based on the data Proposal of resources relevant to the argument
Resources for understanding epistemological activities	Accumulation of information Construction of an argument through discussion

Finally, we analysed how the teacher's responsive practices affected the students' activation of epistemological resources. We used triangulation to enhance the validity of our research.

RESULTS

The teacher's responsive practices to support epistemologically productive practices were shown in two cases; the students' epistemological practices in the argumentation activity differed depending on these responsive moves.

Case of small group 1: Responsive practice for modifying justification

Before the teacher's intervention, the students' discussion focused on the differences between the squid eye model and the human eye model (Table 3), using scientific terms for each part of the eye without any critical evaluation of each other's ideas. In addition, although StA also proposed his own thoughts in their construction of a justification (line 138), he copied what StA wrote down on his worksheet (line 140). This transfer of conceptual resources reflects StA's dependence on StB to make sure he recorded the "correct answers" on the worksheet. We can infer that the epistemological resources activated in this context were *knowledge as a propagated stuff, acceptance of an epistemic authority, proposal of resources relevant to the argument,* and *accumulation of information*.

Table 7. Students' discourse before the teacher's intervention

Line	Student /Teacher	Discourse
134	StB	Let's say this one (pointing at the human eye model) is Model 1 and that one (pointing at the squid eye model) is Model 2.
135	StA	No, I'd like to say that one [squid eye model] is Model 1.
136	StB	Okay, that's fine.
137	StB	In Model 1 (while writing down on the worksheet), visual neurons are … (looking at StC)
138	StA	(continues StB's discourse) On the rear side of the retina.
139	StB	Yeah, it's on the rear side of the retina. (starts to write down on the worksheet)
140	StA	What should I say about this question? Visual neurons are distributed in … (while copying StB's worksheet)
...		
144	StB	Isn't it Model 1 [that could explain the hands-on activity]? (to StA) Hey, look!
145	StC	It says that we need to explain [construct a justification of] the blind spot activity based on the model.
...		
149	StA	What about vitreous humour? What does vitreous humour do? (looking at StB) …

Note. (): Students' actions. []: Researchers' additional interpretation of students' intended meaning.

StC rarely engaged in the discussion but occasionally provided counterarguments or suggestions about his framing of the activity as constructing a justification for their hands-on activity based on the eye models (line 145). This reflected StC's activation of the epistemological resource of *argument with justification based on the data*, unlike StA and StB, who focused on a simple comparison of the two eye structures. However, the other students did not pay attention to StC's suggestions and mostly disregarded his framing of the activity.

When the teacher approached the group during her classroom monitoring, StB asked her what they were supposed to discuss, pointing at the activity question on the worksheet. This implies that StB had also been considering the epistemological framing of the activity. Ms. K attended to this consideration and interpreted that the students were having trouble engaging in the argumentation practices with the activation of productive epistemological resources. She started to engage in the students' discussion, guiding the students to elicit and further their thoughts step by step (Table 4).

Table 8. Ms. K's intervention in small group 1's discussion

Line	Student /Teacher	Discourse
159	Ms. K	So what happened to the mouse in the previous blind spot activity?
160	StB	It disappeared.
161	Ms. K	It disappeared. So which one [of the eye models] did you choose?
162	StB, C	This one (pointing at the squid eye model).
163	Ms. K	… (picking up the squid eye model) Then, could you tell me the justification you constructed with this model?
164	StB	Explain what? (looking at Ms. K)
165	Ms. K	Why the mouse has disappeared.
166	StB	Because the retina has reached its limitation.
167	Ms. K	Because the retina has reached its limitation.
168	StB	Because of the small size of the pupil?
169	Ms. K	(pauses for a while) Oh, so what you mean by "the small size of the pupil" is that the light coming through the pupil is…
170	StB	Yeah, the amount of light coming through the pupil is too low.
171	Ms. K	Because the amount [of light] is too low.
172	StB	Because there's no limitation on the light …
173	Ms. K	So, to rephrase, what you mean by the limitation is … is it in terms of the amount? The amount of light?
174	StB	Yeah. (nodding his head while looking at Ms. K)
...		

177	Ms. K	Well, let's think of whether our ideas are appropriate to explain the result of the activity. For instance, when there's a limited amount of light, just like what we just discussed, how would our vision be like? If the amount of light is too low…
178	StB	Blurry?
179	Ms. K	Yeah, umm, blurry? Blurry is not quite a concrete explanation. Well, in what occasion do we say that the amount of light is low?
180	StB	At night.
181	Ms. K	At night… so how does it look at night?
182	StB	Can't see anything.
183	Ms. K	Then … when the night is coming, how does it look?
184	StB	I can only see shapes of objects, not their colours.
185	Ms. K	So is that what blurry looks like?
186		(students stare at Ms. K without any discourse)
187	Ms. K	In the activity, there were both the magician and the mouse. How was the magician shown?
188	StC	It was shown very clearly.
189	Ms. K	We could see the magician very clearly, but only the mouse disappeared. Let's think of how to explain that, let's think of it. How could we justify that phenomenon with this model (picking up the squid eye model)?

Note. (): Students/'teacher's actions. []: Researchers' additional interpretation of the intended meaning.

Ms. K asked the students to explain the results of the blind spot activity and then asked for a justification of the results based on the eye model that the students had chosen (lines 159-163). Such questions indicated how the teacher framed the students' process of constructing a justification. However, StB asked Ms. K about what they were supposed to justify (line 164), indicating that the students did not share the same epistemological framing as Ms. K; in particular, they were unable to activate the epistemological resource such as *argument with coherent justification based on the data*. To support the students' activation of this resource, Ms. K guided the students in reframing their results in the hands-on activity as the data in their argument (line 165).

StB provided his ideas as justification, focusing on using scientific terms that they had previously learned in the lesson about eye structure. Ms. K repeated StB's words with a tone that implied an evaluation of conceptual correctness. It led the students to keep searching for different parts of the eye structure to construct other justifications, without critically evaluating their reasoning. Ms. K reflected on this moment in her interview after the class;

> The best advantage of this activity I felt in this class was that I could understand what kind of concept the students possess and what kinds of thoughts they were having at the moment. I didn't care about students' everyday thoughts before, but as I was eliciting their thoughts [in this class], I kept trying to figure out what they were thinking … and then support them with additional questions to advance their thoughts. … when

> the kids mentioned scientifically incorrect ideas, I kept asking additional questions as I used to do before. So they could have noticed [that their thoughts were scientifically incorrect] through this kind of difference in my practices. … So it remained an unsolved question, how much support would be appropriate for me to provide to the students.

From the interview, we can infer that Ms. K was constantly concerned about the balance between eliciting the students’ everyday thoughts as productive resources and leading them to the scientific concepts. Although Ms. K constantly repeated StB’s words, which indicated that she focused on the correctness of the students’ ideas, she started to shift her attention towards the intention behind StB’s words (line 173). To further elicit StB’s ideas, Ms. K asked for a critical evaluation of the idea within the group (line 177). Moreover, she demonstrated how they could critically evaluate the idea to modify the justification. Specifically, she asked for a more precise description of StB’s everyday experience that was transferred in the discussion, revealing his conceptual resource more concretely. Through these discourses, we can infer Ms. K’s intention to foster a context for the students to activate the epistemological resources *knowledge as a fabricated stuff, critical evaluation of justification based on the data,* and *construction of an argument through discussion*. She then asked, in the form of a rebuttal of the student’s idea, for a comparison of the activated resource and the phenomenon they experienced in the blind spot activity (line 185). This supported the shift in their attention from a conception about the eye structure to the logical validity of the justification based on the data. Overall, by interpreting the students’ confusion about the epistemological framing of the argumentation activity, Ms. K tried to support the students so that they could share a critical evaluation of their ideas to construct a valid argument.

At the end of the intervention, StC engaged in a discussion where the group adjusted their data so that they could use it to construct an argument, showing an effort to engage in the critical evaluation of the argument. Right after Ms. K’s intervention, StA told StB, “Your confidence went down” indicating that the student’s perception of StB’s authority had diminished. StB then started to ask the other students for ideas and said, “Let’s interpret these models as we want to. It’s okay to construct justifications on our own, and we can express our thoughts in our own words.” These practices demonstrate the students’ activation of epistemological resources, which the teacher tried to support in her intervention.

Although the students occasionally shifted back to asking for a transfer of the “correct answer” and relying on epistemic authority such as textbooks when they could not propose new ideas (line 285), no one provided definitive answers and they kept proposing new justifications and sharing critical evaluations of them (Table 5). However, when the students did not complete the construction of a group argument and the teacher announced their lack of time for discussion, they stopped this productive practice and shifted back to filling in the blanks on their worksheets, which indicated the activation of the epistemological resources a*ccumulation of information* and *acceptance of an epistemic authority* once again.

Table 9. Students' discourse in small group 1 after Ms. K's intervention

Line	Student /Teacher	Discourse
…		
283	StB	When we look at objects with this eye structure (picking up squid eye model), our brain … (mumbling while writing down on his worksheet)
284	StA	Why did you think this one [the squid eye model] is the one?
285	StB	I'm not sure, but it is similar to that (pointing at the eye structure diagram on the blackboard)
286	StA	But this one has optic nerves on the back [of the retina].
…		

Note. (): Students' actions. []: Researchers' additional interpretation of the intended meaning.

Case of small group 2: Responsive practice for developing justification and rebuttal

In small group 2, before the teacher's intervention, the students discussed whether they agreed with a claim provided on the worksheet that said, "Squid eyes are more evolved than human eyes because they don't have a blind spot." StE suggested that they needed to develop a justification for this claim that included a comparison of squid eyes and human eyes, starting a discussion to construct a justification (Table 6).

The students' discourse indicates that the difference between the activated epistemological resources of StD and StE persists. Unlike StD's consideration of a form of valid justification, StE continued to assert that there should be a comparison of squid and human eye structures because the argumentation question involved a comparison of these two subjects (lines 372-374). This indicates that StD and StE activated different epistemological resources in the category of "understanding epistemological forms", with StD activating *argument with justification* and StE activating *argument with justification and qualifier* to uphold the claim against the counterargument. They did not resolve this issue, and StD stopped trying to discuss it with StE. Instead, she asked for corroboration of her argument from a student in another group in an attempt to prove the validity of her thoughts (lines 375-382).

Table 10. Students' discussion before Ms. K's intervention

Line	Student /Teacher	Discourse
372	StE	… don't we have to mention that squids have blind spots and we don't … if we want to justify our claim? Isn't it how we can mention the difference between human and squid?
373	StD	Well, that one [evidence card] could be used to justify the claim saying that squid's eyes are more evolved. We should use that one [another evidence card].

374	StE	So this card is saying that human eyes have blind spots and therefore we cannot see the rear view, right? Doesn't it support this claim [that squid eyes are more evolved]?
375	StD	Hey (calling student Oth in another small group). … which one did you choose as the one that supports the claim? You did choose this one, right? [The evidence card saying that] Squids don't have a blind spot on their retina.
376	Oth	I did.
…		
380, 382	StD	(to Oth) … She [StE] told me to write down that there's a blind spot on the human retina. …
…		
400, 402	StD	I think squids' eyes are more evolved because they can see everything [with a wider view].
...		
404	StB	But squids cannot distinguish colours.
405	StG	Yeah, that's a drawback [of the squids' eyes].
406, 409	StD	It cannot distinguish colours but … they can see multiple things [with a wider view] since they don't have a blind spot.
…		
414	StE	No, please hear me out. The reason I've put this evidence card here [as the one supporting her claim] is this one [human eye] has blind spots but that one [squid eye] doesn't. That's what we are supposed to explain … because there's a possibility that both of them possess it [a blind spot]. But we are telling them that this one has it [a blind spot] but that one doesn't. Do you get it?

Note. (): Students' action. []: Researchers' additional interpretation of the intended meaning.

Without aligning their activation of epistemological resources for understanding epistemological forms, the students continued to discuss how the existence of a blind spot would affect vision (lines 400-409). They focused on activating various conceptual resources in their discussion, showing the activation of the epistemological resource *proposal of resources relevant to the argument*, but they did not respond to each other's ideas, showing a limitation on activating the resource *critical evaluation of justification based on the data*. Then, after StE pointed out her thoughts on constructing a valid justification again (line 414), the students ended the discussion, writing down on their worksheets an argument that was not agreed upon. This showed a change in their activation of epistemological resources for understanding epistemological activities from *construction of an argument through discussion* to *accumulation of information*. StB then asked for Ms. K's help (Table 7).

Table 11. Ms. K's intervention in small group 2

Line	Student /Teacher	Discourse
429	StE	Ms. K, is it impossible for us to differentiate colours if we don't have any visual cells that differentiate colours?
430	Ms. K	Don't you think so? So you think it's an important factor?
…		
433	StE	Yes, I think it is.
434	Ms. K	Then you can write that down. Because that's a main factor [that could decide the more evolved eye structure]
435	StD	Hey (to Oth), then, if they [squids] see sharks in blue, (()) would get eaten. Right? How about squid ink? What if they see squid ink in blue? …
436	StE	Ms. K, could we see the rear view if there was no blind spot on the retina?
437	Ms. K	What do you need on the rear side in order to get the rear view?
438		(StD,G) Eyes. | (StE) Blind spot? | (StD) Visual cells.
439	Ms. K	Visual cells. So, could they get the rear view?
440	StE	In that case, isn't it impossible to see in that angle?
441	Ms. K	First of all, isn't the light coming in from the rear side needed as well?
442	StE	So it's impossible, then.
443	StD	Oh.

Note. (): Students' actions. []: Researchers' additional interpretation of the intended meaning. (()): Unintelligible recording. | : Discourses spoken at the same time.

Ms. K started to join the discussion by responding to StE's question. She responded by asking the students whether thought that noticing colours was a factor that determine the more evolved eye structure. This reflected her epistemological framing of the activity, constructing an argument by discussing a factor that could determine which eye structure was more evolved. This implies the necessity to consider the respective features of squid and human eyes, supporting StE's activated epistemological resource of *argument with justification and qualifier*.

StD then asked another question about the existence of a blind spot. Ms. K attended to the conceptual aspect of StD's justification, interpreting that the students did not understand the concept of a visual pathway. She tried to elicit the concept from the students by asking them what they need to get a rear view. The students' answers varied, and the teacher attended to the range of the answers, interpreting that the students did not know which specific structure was necessary for visibility and that their speculation was based on this confusion. Furthermore, she could interpret that the students did not reach a consensus on an argument, which indicated a lack of activation of the epistemological resources *argument with coherent justification based on the data* and *construction of an argument through discussion*. She responded to them with conceptual support by pointing out that the direction of the light coming into the eye is the factor that determines range of the vision. It also provided the students another example of justification that incorporates consideration of the difference between squids' and human eyes, facilitating activation of productive epistemological resources.

After the teacher's intervention, the students shared Ms. K's and StE's epistemological framing and started to discuss the justification based on a comparison of squid and human eye structures (Table 8). StE constructed a rebuttal of the provided claim (line 444) and developed its justification further with specific conceptions about eye structure and visual cells. The students also fostered their justification by bringing up their everyday experiences, proposing critical opinions about each other's ideas. Such discussion after the teacher's intervention demonstrated the activation of productive epistemological resources, namely *knowledge as a fabricated stuff, argument with coherent justification based on the data, critical evaluation of justification based on the data*, and *construction of an argument through discussion*, indicating their epistemologically productive practice.

Table 12. Students' discourse after Ms. K's intervention in small group 2

Line	Student /Teacher	Discourse
444	StE	See? So that's the same [in both squids and humans]. But this one [squids] cannot perceive colours, so we win.
451	StD	(to Oth) There should be visual cells for the rear side as well. … There should have been light coming in that side in the first place, but the light cannot enter from there.
…		
454	StE	I disagree with this claim [provided on the worksheet]. Since human eyes have visual cells that can differentiate colour and squid eyes don't, human eyes are more evolved than squid eyes. For instance, as you know, we determine whether food is going to be delicious based on its colour. What do you think about this? …
…		
460	Oth	Let's say there's a black chicken.
461	StE	Yeah, that's what I'm talking about.
462	Oth	But what if it's delicious?
463	StD	(laughs)
464	StE	Let's say we are living in a world of black and white. How dreadful it would be.

Note. (): Students' actions. []: Researchers' additional interpretation of the intended meaning.

CONCLUSIONS AND IMPLICATIONS

The cases showed the teacher's efforts to the attend to students' thinking behind their utterances and how she elicited and responded to the students' epistemological features to facilitate productive practices. Specifically, the teacher supported the students' activation of productive epistemological resources by eliciting and interpreting the students' thoughts in terms of how they constructed their arguments. She paid more attention to how the students justified the results of their activity, such as their everyday experiences that were applied to the justification or the conceptual resources they focused on as an important factor to support their claim. She then responded to the students' arguments by rebutting the incoherence of their ad hoc justifications, guiding the students to further reconsider their justifications instead of imposing her thoughts over their thoughts. The teacher's responsive teaching fostered the context for the students to modify their justifications by advancing the epistemological aspects of their argumentation practices.

This research identified a teacher's responsive teaching approaches to argumentation, which is a core practice of authentic scientific practice and has a significant effect on students' epistemological support. The study expands the understanding of the role of responsive teaching in supporting students' epistemologically productive practices and authentic scientific practices.

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THE EFFECT OF TEACHING STRATEGIES ON 4TH GRADE CHILDREN'S SCIENTIFIC REASONING SKILLS

Erzsébet Korom[1], Enikő Bús[2] and Mária B. Németh[3]
[1,3]Institute of Education University of Szeged, Hungary
MTA-SZTE Science Education Research Group
[2]Doctoral School of Education, University of Szeged, Hungary
MTA-SZTE Science Education Research Group

An increasing number of countries in the world admit the outstanding importance of high-quality teachers. Studies have started to focus on teachers' effectiveness through the examination of the relationship between teaching strategies and student performance. The first aim of our research is to examine whether the strategies favoured by Hungarian teachers are consistent with the international findings; then, we will explore the relationship between the identified strategies and children's scientific reasoning skills at classroom level. We hypothesize a correlation between classroom teachers' teaching strategy and children's performance. Our research consists of two parts: (1) a teachers' questionnaire about teaching and (2) an assessment of students' reasoning skills. The online data collection was carried out in 2015 among 237 classroom teachers and 4010 primary school students in Grade 4. The teachers' questionnaire consists of 30 items; the scientific reasoning test consists of 64 items. The reliability of both assessment instruments *was good (questionnaire: Cronbach's alpha=.81, test: Cronbach's alpha=.85). We have directly linked each teacher to his/her classroom; therefore, we received more accurate results than school level-based studies. In line with international findings, we identified three subscales of teaching strategy by using factor analysis (KMO=.785): teacher-directed, cognitive-activation and active learning strategy. The most commonly used instructional strategy is teacher-directed, which is followed by the cognitive activation and the active learning strategy. Active learning is the only strategy that shows correlation with the scientific reasoning test (r=.22, p<.05), and teachers who have participated in in-service training programmes about teaching science subjects use active learning methods more frequently (r=.18, p<.01). Considering these results, we have to offer more opportunities for teachers to expand and improve their teaching techniques to encourage active learning strategies in the classroom.*

Keywords: teaching methods, primary school, scientific reasoning

THEORETICAL FRAMEWORK

The success of education is influenced by many factors, and one of the key elements is the teacher. The outstanding importance of high-quality teachers is more and more recognised all over the world. Several research projects focus on the study of teachers' knowledge, beliefs and self-efficacy, and an increasing number now focus on teacher's effectiveness through the examination of the relationship between teaching strategies and student performance, e.g. Catalano, Perucchini and Vecchio (2014); Samson, Enderle and Grooms (2013). Due to international student assessments, many background studies started to examine the extent of different effects on student performance. Schroeder, Scott, Tolson, Huang and Lee (2007) looked at the effects of teaching strategies on student achievement in science. They analysed sixty-one studies and identified 8 teaching strategies. The main message of this study is that alternative teaching strategies exerted a positive influence on student achievement when compared with the traditional teaching methods used in the instruction of the control groups.

The direct antecedent of our research is the OECD's 'Teaching Strategies for Instructional Quality' research, which is based on the analysis of the TALIS-PISA link database (OECD, 2016). The OECD linked the PISA 2012 mathematics results to the teaching strategies part of the TALIS questionnaire to gain some insight into teachers' effectiveness in the 8 participating countries. This research identified three main teaching strategies at school level: active learning, cognitive activation and teacher-directed instruction (Table 1). Student discussions, teamwork, cooperation and both peers' and tutor's reflexions play a key role in the use of active learning. The cognitive activation strategy uses instructional methods that create challenges for students engaging their higher order thinking skills to solve the problem. Teacher-directed instruction is clear, simple and easy to follow; requires no complex thinking skills.

Table 1. Teaching strategies among mathematics teachers based on their classroom practices (OECD, 2016. p. 2)

Active learning	Cognitive activation	Teacher-directed instruction
• Consists of promoting the engagement of students in their own learning. • Under this strategy, students' discussions, group work, co-operation, reflection and the necessary support to foster these activities play a central role. • Furthermore, the inclusion and use of information and communication technologies (ICT) in the classroom can help to foster an interactive and individual learning environment.	• Refers to the use of practices capable of challenging students in order to motivate them and stimulate higher-order skills, such as critical thinking, problem solving and decision making. • This strategy not only encourages students to find creative and alternative ways to solve problems, but enables them to communicate their thinking processes and results with their peers and teachers.	• Refers to teaching practices that rely, to a great extent, on a teacher's ability to deliver orderly and clear lessons. • Making explicit the learning goals, providing a summary of previous lessons or asking short, fact-based questions are examples of practices that help to structure lessons.

According to the TALIS-PISA results, students learning through the cognitive-activation strategy achieved significantly better results than others. The teacher-directed strategy is mostly used among lower-preforming students. Thus, the teacher-directed strategies can help students succeed on easier tasks, but they may not be the best strategy in the long run to prepare students for more complex tasks. The study did not find any significant connection between the strategies used and the level of students' engagement. Teachers working at the same school tend to use similar strategies, and the teachers in schools with students from disadvantaged socio-economic background tend to have fewer opportunities to attend further training. This research focuses on mathematics teachers and the mathematics performance of 15-year-old students. For the development of our teachers' questionnaire, we took the TALIS-PISA link data analysis into account, but we also examined younger students, and the students' scientific thinking. Our research is highly relevant because very little data is available about the instructional methods used by Hungarian classroom teachers and their impact on students' scientific knowledge. Most importantly, we have examined one of the main components of scientific knowledge: scientific reasoning skills.

There is a growing need to learn the methods of science along with science content. Scientific reasoning is an important component under the cognitive strand of 21st century skills and is highly emphasized in the new science education standards (Zhou et al., 2016). There is a greater emphasis on general reasoning skills needed for open-ended scientific inquiry (Bybee & Fuchs, 2006). Scientific reasoning can be defined as international knowledge-seeking and coordination of theory and evidence (Kuhn, 2002). This process of knowledge acquisition change encompasses the abilities to generate, test and revise theories and hypotheses, and to reflect on this process (Kuhn & Franklin, 2007; Wilkening & Sodian, 2005; Zimmerman, 2007). Scientific reasoning skills include the ability to systematically explore a problem, formulate and test hypotheses, control and manipulate variables, and evaluate experimental outcomes (Bao et al., 2009; Zimmerman, 2007). Scientific reasoning is important for participation in the knowledge society as an autonomous, critical thinker and is a key part of so-called 21st century skills (Fischer et al., 2014; Osborne, 2013). Traditionally, developmental psychologists argued that scientific reasoning skills emerged only during adolescence (Inhelder & Piaget, 1958). In contrast, in the last 20 years developmental research has found plenty of evidence for the existence of early competencies (Bullock, Sodian, & Koerber, 2009; Zimmerman, 2007). Research findings indicate the appearance of basic experimentation and evidence evaluation skills in preschool and elementary school children.

AIMS

The aim of our study was to twofold. First, we explored the underlying factors of teachers' teaching strategies in 4th grade science class. Secondly, we looked at the effects of the teaching strategy used on students' scientific reasoning performance. In line with the OECD research, we hypothesized that teacher-directed strategies and cognitive activation strategies are used the most by the teachers, while active learning strategies are used less often. We predicted a connection between teaching experience and the strategies used. As the test measured scientific reasoning skills and inquiry skills, we expected students using cognitive activation and active learning strategies to perform better.

METHODS

Sample

The sample of the present study was drawn from the Hungarian Education Longitudinal Program (HELP), in which 4010, 4th grade students of 206 classes of 113 schools participated (Table 2). The sex ratio in the students' sample is balanced.

The teachers' questionnaire was completed by the science teachers working in the participating classes, and all together 237 primary school teachers participated in our research. The average age of teachers in the sample is high; half of the teachers are older than 50 years and have more than 30 years of experience (Table 2). The sample is reasonably typical of Hungarian conditions (Eurostat database, 2017). The average age of Hungarian teachers is high (around 40 years old), most of them are women; there is a shortage of male teachers and science teachers as well. Most of the lower elementary teachers in our sample have a degree from a teacher training college and teach in Grades 3 and 4. Only 5% of our sample has got a university degree. Almost 80% of the teachers participated in in-service teacher training in the past 3 years. Based on the available data, we linked and analysed the achievement data of 2618 students and the teaching strategies of 135 teachers.

Table 2. Characteristics of the teachers and students

Teachers	Students
Number of teachers: 237	Number of students: 4010
Females: 96.2%	Females: 50.5%
Average age: 47.8 years (SD=8.6)	Grade: 4
Qualifications: 93.2% college degree	Number of classes: 206
Average professional experience: 25.0 years (SD=10.5 years)	Number of schools: 113
Further training: 78.4%	

Measurements

To explore teaching strategies, we composed a self-reported questionnaire based on the TALIS items (OECD, 2014). Besides background variables (gender, age, qualifications, professional experience, in-service training) we identified the use of instructional methods using 22 items. 9 of the items were the same as those used in the TALIS study. The questionnaire consists of three subscales with one subscale for each of the three strategies. Six items belonging to the active learning subscale examine the frequency of the students' experiments, short presentations, projects and the out of school social activities during science classes. Nine items of the cognitive activation subscale measure the use of discussions, debate, problem-based assignments, the presentation of the connection between science and everyday life; and seven items of the teacher-directed strategy subscale assess the emphasis teachers put on the transfer of the curriculum, on highlighting the essential elements, on practicing the assignments and on helping students lagging. We used a four-point Likert scale (1 = never, 2 = rarely, 3 = often, 4 = always).

The online Scientific Reasoning test consists of two subtests (Table 3). One of the subtests measures some basic reasoning skills with 29 alternate or multiple-choice items. In order to complete the tasks students had to operate different thinking processes such as conservation; proportional, correlational, probabilistic reasoning and classification skills in science context (Figure 1). These reasoning skills are the general components of thinking, and they play a fundamental role in the acquisition of scientific knowledge.

The inquiry skills subtest consists of 35 items assessing different types of inquiry stages: identifying research questions and hypothesis, designing experiments, interpreting data and drawing conclusions (Figure 2). These skills are important components of scientific knowledge and the knowledge acquisition process.

Table 3. The subtests of the Scientific Reasoning test

Subtest		Number of items	Cronbach's alpha
Reasoning skills	Conservation Proportional reasoning Inductive reasoning Classification	29	.74
Inquiry skills	Identifying research questions Designing experiments Identifying variables Interpreting data Drawing conclusions	35	.77
Total test		64	.85

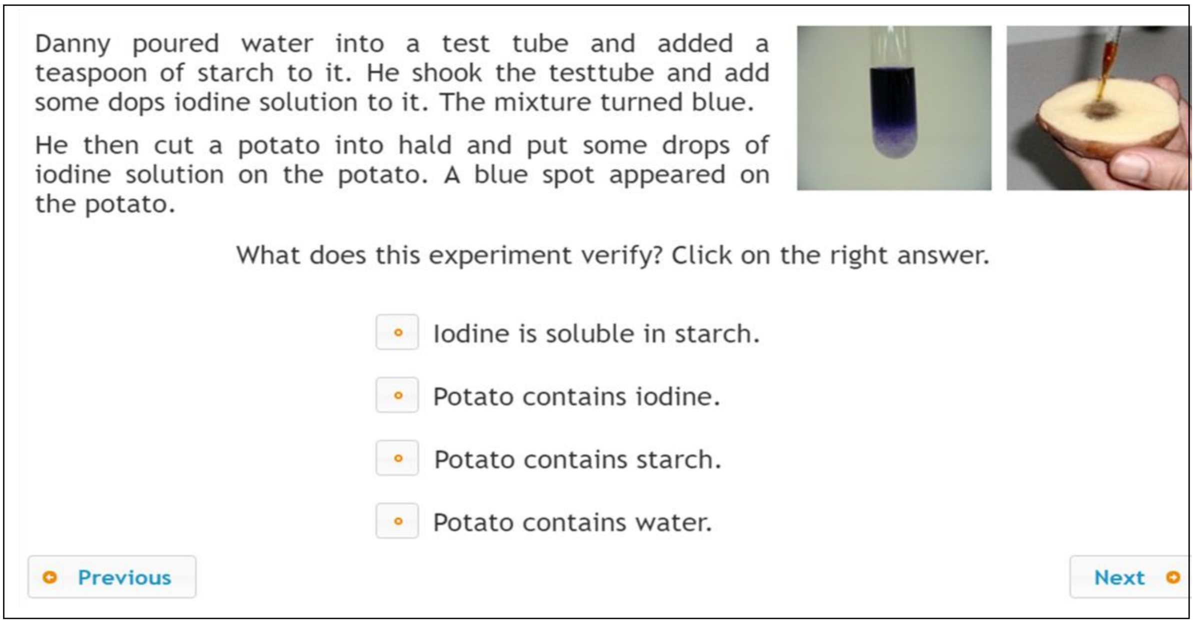

Figure 1. An example of measuring proportional thinking in the Scientific Reasoning test

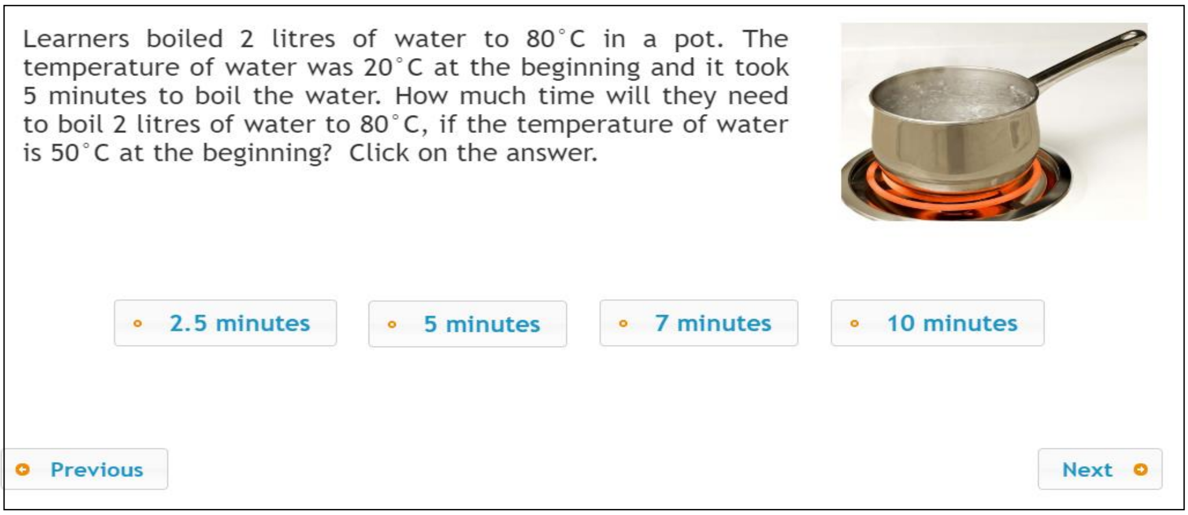

Figure 2. Analysis of the experiment and drawing conclusion – A sample item for measuring the inquiry skills in the Scientific Reasoning test

Data collection was carried out in May 2015. The assessments were carried out in the schools' ICT rooms by means of the eDia (Electronic Diagnostic Assessment) system. Students completed the online tasks by clicking on or moving objects on the screen by dragging-and-dropping. Immediate feedback was given after test completion.

RESULTS

The reliability of the questionnaire was good (Cronbach's alpha=.81). As a result of the exploratory factor analysis (KMO=.785), we identified three subgroups in line with the TALIS-PISA link report (OECD, 2016): active learning, cognitive activation and teacher-directed strategy. During the analysis, we summed the scores of the items belonging to the same subscales. The most commonly used instructional strategy is teacher-directed, which is followed by cognitive activation and the active learning strategy (Table 4).

Table 4. The frequency of teaching strategies uses among teachers (N=237)

Subscales	Mean (%)	SD (%)
Active learning	51.9	9.0
Cognitive activation	73.2	9.1
Teacher-directed strategy	80.2	9.5

The correlation analyses between teaching strategies revealed that the strongest correlation is between the use of active learning and cognitive activation strategy ($r=.47$, $p<.01$), while the teacher-directed strategy shows a stronger correlation with the cognitive strategy ($r=.31$; $p<.01$) than with the active strategy ($r=.14$, $p<.05$).

We found no difference in strategy use based on age or teaching experience. For the background variables, the only correlation is in the case of in-service professional training: those who have participated in in-service training programmes on teaching science subjects, are the ones who use active learning methods most frequently.

The scientific reasoning test proved to be reliable (Cronbach's alpha=.85). The results of the inquiry skills subscale are significantly higher than the reasoning skills measured on scientific content (paired samples statistics $t=-20.252$ $p<0.01$). Broken down by gender, girls' performance is higher on both the complete test and on the subtests as well (Table 5).

Table 5. Students' scientific reasoning achievement (N=4010)

Scientific Reasoning Test		Total sample		Boys		Girls	
		Mean (%)	SD (%)	Mean (%)	SD (%)	Mean (%)	SD (%)
Sub-test	Reasoning skills	50.1	15.5	48.9	15.6	51.4	15.4
	Inquiry skills	54.3	15.6	52.3	16.0	56.3	15.1
Total test		52.4	14.1	50.8	14.4	54.1	13.7

To examine the correlations between teaching strategy and science test results, we compared the teachers' total scores on the three subscales to the results of the 4th grade students' who they taught (N=2618). Only the active learning strategy shows a significant correlation with the scientific reasoning test ($r=.22$, $p<.05$) and the inquiry skills subtest. and the inquiry skills subtest ($r=.24$, $p<.05$). Among the examined 22 items, performance is positively correlating with 3 subscales of active learning: 'We make student presentations.' ($r_{reasoning\ skills}=.34$; $r_{inquiry\ skills}=.32$; $r_{total\ test}=.34$ $p<.01$); 'We conduct student experiments according to my instructions.' ($r_{reasoning\ skills}=.25$; $r_{inquiry\ skills}=.25$; $r_{total\ test}=.26$ $p<.01$); 'We visit out of school places (e.g. zoo, museum, nature trail).' ($r_{inquiry\ skills}=.25$; $r_{total\ test}=.21$ $p<.01$). The teacher-directed item of 'I help those, for who the learning material is too difficult.' correlates negatively with the test performance ($r_{reasoning\ skills}= -.23$; $r_{inquiry\ skills}= -.28$; $r_{total\ test}= -.27$ $p<.01$).

DISCUSSION AND CONCLUSIONS

Our data suggest that Hungarian primary teachers in the science lessons prefer frontal methods with teacher-directed processing and practicing of the instructional material. The cognitive activation strategy, in which students are given the opportunity to discuss the issues raised and to get to know the social relevance of the learning material, is used with a similar frequency. The least typical strategy in the classroom is a method relying on students' active participation (e.g. student experiments, project work, presentations, inquiry-based learning). This could be explained by the learning material, which is a large amount and is very much knowledge-oriented already in the early phase of learning, which has an effect on teaching strategies. Teachers concentrate on the transmission of knowledge and to teach the basic terms and relationships, therefore, they have little time for an active student activity, for inquiry, examination and to discuss experiences.

The other factor that influences the differences found on the use of diverse instructional strategies could be teachers' preparedness and their existing methodological knowledge. Our results are in accordance with previous research results (see for example Hódi, B. Németh & Tóth, 2017; Rice, 2010). They show that teaching experience has less influence on the instructional methods used by the teachers, it only plays a role during the initial phase. Our data show that the in-service training programmes have a higher impact on the use of active learning strategies – which are the most effective in the development of scientific reasoning –, than teaching experience has. Our research draws attention to the importance of in-service teacher training, and to the key importance of the integration of modern teaching methods into classroom practice.

We would expect that in the development of scientific thinking both cognitive and active strategies have a demonstrable effect. Our data, however, only confirmed the role of active learning strategies. This can be explained by the nature of the test. The inquiry skills subtest measured such skills, of which development can be promoted by active learning methods, like student observations, examinations, student experiments facilitated by the teacher.

LIMITATIONS

The teachers' questionnaire used self-report. As a next step, we could analyse actual teaching practice through video-analysis on a smaller sample, and it would be necessary to ask the students on the applied teaching and learning methods during science lessons. The examined teaching strategies explain the differences between students' performance to a small extent. To understand the further effects, it would be necessary to reveal students' affective features and socio-cultural background, and other features of the learning environment. Our research focused on the early phase of scientific learning, when according to age characteristics, both the nature of the curriculum and the teaching strategy is different than in the latter phases. Teachers' qualification varies as well. From 1st to 4th grade, mostly teachers with college degree teach science, while from 5th grade – with the beginning of the disciplinary education – subject teachers with scientific qualification participate. Therefore, it would be advisable to extend the research to the upper elementary school and to secondary school as well.

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TEACHERS' KNOWLEDGE FOR TEACHING CHEMICAL BONDING: SCOPE AND TRAJECTORIES

Marissa Rollnick[1], Rene Toerien[2], Doras Sibanda[3], Annemarie Hattingh[2] and Vanessa Kind[4]
[1] Marang Centre, School of Education, Wits University, South Africa
[2] School of Education, University of Cape Town, South Africa
[3] School of Education, University of KwaZulu-Natal, South Africa
[4] School of Education, Durham University, UK

Chemical Bonding is a central concept in the study of chemistry. It is foundational in that it is difficult for chemistry students to progress without understanding how and why atoms bond. Research over several decades shows multiple conceptions and misconceptions of bonding in the student population. Given the abstract nature of the topic these incorrect ideas must originate in teaching. This paper thus focuses on the extent to which teachers succeed in taking student ideas into account through their topic specific knowledge for teaching the topic, also known as Pedagogical Content Knowledge (PCK). The paper analyses three aspects of teacher knowledge from three studies – how their PCK for teaching chemical bonding develops through their career, whether short term workshops can make an impact on their PCK and how a group of teachers sequence material for teaching chemical bonding. The findings show that events over the careers of teachers can play a significant role in shifting their teaching approaches, from being textbook bound and teacher-focussed, to including students' ideas into their teaching strategies. Significant events include professional development opportunities, teaching experience and the input from colleagues and students. The attendance of short term workshops can show both short and long term gains. The long term gains depended on whether they taught the topic shortly after the workshop. Changes in the curriculum also played an important role in determining classroom practice with sequencing of concepts being a key issue. In the study reported teachers do not get much assistance from curriculum documents and evolve their sequencing largely from their determination of student difficulties from research on teaching and learning and the logic of the content structure. Overall the findings connect well to the components of the model used in the first study and show that events throughout the careers of teachers can play an important role in shaping the career trajectories

Keywords, chemical bonding; sequencing, PCK

INTRODUCTION

Feiman-Nemser (2001) views learning to teach as a life-long endeavour, a learning continuum that starts with pre-service training and ends when a teacher permanently leaves the profession. Teacher learning can therefore be viewed on a trajectory over an entire career, some learning being planned and intentional, for example participating in formal professional development activities, but more likely entailing learning that is incidental and unplanned, as a result of larger and smaller events that happen on a daily basis. Mapping the scope and trajectories of teachers' knowledge for teaching, by investigating the impact of significant events, such as professional development activities, the influences of changes in the curriculum, and the impact of classroom experience, can provide insight into how to better support teachers and shorten the route to expertise. These influences may lead to changes in patterns of sequences in teaching a particular topic or shifts in knowledge of different explanatory frameworks after a topic specific workshop.

This paper investigates the above changes in the context of chemical bonding, a crucial component of high school chemistry courses which needs to be rigorously taught to avoid confusion in later studies. The topic is taught using a variety of explanatory frameworks (Taber, 2002). Teaching this topic requires thoughtful application of such frameworks. Chemical bonding is abstract hence misconceptions held by learners are likely to arise from teaching.

The paper considers two aspects of teacher knowledge development - the career trajectories of their knowledge for teaching chemical bonding and the influence of significant events, such as participation in professional development activities, changes in the curriculum, and teaching experience on their PCK for teaching the topic. The study was guided by the following research questions.

1. How can teacher learning trajectories for teaching chemical bonding be mapped?
2. What is the impact of a one-day workshop on teachers' *knowledge for teaching* chemical bonding?
3. What patterns of learning sequences do teachers use for teaching bonding?

LITERATURE

Chemical bonding is a topic where understanding is developed over time, through multiple models. Students need to be able to interpret multiple symbolic representations of a chemical bond (Tan & Taber, 2010). One of the goals in science teaching is to facilitate deeper understanding of the science content amongst students. Students start off with a very basic understanding of bonding, but, over time, they expand their understanding by including more sophisticated models (Taber, 2003). The teaching of chemical bonding should therefore facilitate this expansion of students' content understanding, shifting their understanding beyond viewing bonds as shared or transferred electrons to seeing bonding as electrostatic interactions, and then as interactions between orbitals (Taber, 2002).

There is evidence that students' difficulties with chemical bonding may emanate from the use of certain teaching models. For example, Levy Nahum, Mamlok-Naaman, Hofstein, and Taber (2010, p. 185) argue that students had difficulties 'finding a model of melting and vaporization, which enabled bonds to form when particles were in close contact.' Dhindsa and Treagust (2014) argue that the difficulty in understanding chemical bonding is linked to a teaching sequence that starts from ionic, covalent and polar covalent bonding. In most countries, curricula are designed based on a constructivist approach which favours a sequence starting from covalent, polar covalent and ionic bonding.

The investigations were framed theoretically by the understanding that teachers transform their knowledge of a specific topic (Content Knowledge, or CK) using their knowledge of learners to develop specialised knowledge for teaching, referred to by Shulman (1986) as pedagogical content knowledge (PCK). Despite debates surrounding PCK (Kind, 2009) there is now substantial agreement that PCK is topic specific (Aydin, Friedrichsen, Boz, & Hanuscin, 2014; Gess-Newsome, 2015) and can be differentiated as either personal or collective (Gess-

Newsome, 2015). Collective PCK relates to shared teacher knowledge while personal PCK refers to knowledge implemented in practice taking context into account. A necessary precursor of PCK is knowledge of the relevant content of the topic to be taught (Kind, 2009).

PCK has been modelled in various ways (e.g. Gess-Newsome, 2015; Magnusson, Krajcik, & Borko, 1999) and multiple components have been considered essential for its development. Common to most models are two components emphasised in the intervention in this study, namely *knowledge of student prior knowledge* and conceptual *teaching strategies*. These two components are considered canonical knowledge as they appear in the Topic Specific Professional Knowledge (TSPK) box of the Gess Newsome (2015) model. Toerien (2017) modifies this model slightly to include a topic specific content component in the second box which she renames as Topic Specific Knowledge for Teaching (TSKFT).

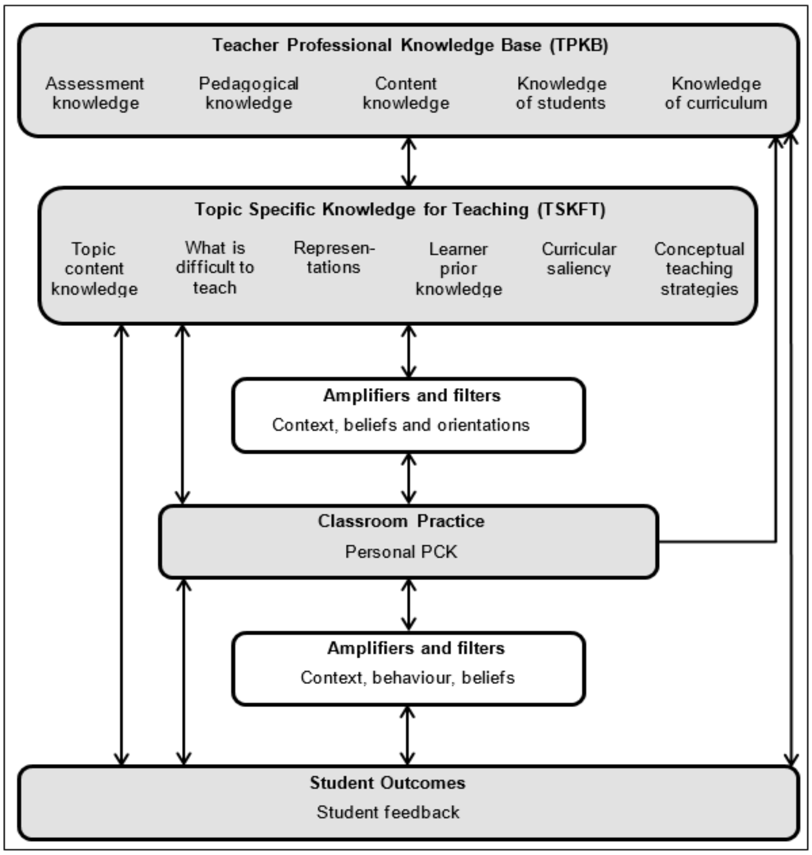

Figure 1: Adapted Model of Teacher Professional Knowledge and Skill, including PCK (Toerien, 2017)

Teaching is a complex endeavour with many different long term and short term experiences playing a role in the growth of knowledge. Long term influences include teaching experience (Hashweh, 2005) and gaining further qualifications (Toerien, 2017). Other influences may be short term single events such as a one-day workshop on a specific topic.

Daehler, Heller, and Wong (2015) draw several lessons from their experiences with three interventions in science education, the most recent being "Making sense of science". They conclude that professional development activities can be employed to improve teacher PCK, outlining several key ingredients that contribute to PCK growth, including the intertwining of science learning with teaching, high quality teacher learning experiences that model exemplary instruction, an emphasis on deep conceptual understanding of the content in both teaching and learning and the leverage of collaborative sense making. Luft and Hewson (2014) argue that it would be useful for future professional development interventions to investigate how teachers learn about a concept. In this paper we look at a conceptually based short term intervention based on chemical bonding.

METHOD

To answer the first question, the learning trajectories of a group of experienced chemistry teachers in South Africa were mapped with respect to their topic specific knowledge for teaching (TSKFT) chemical bonding (Toerien, 2017). A multiple case study design was followed with in-depth interviews providing insight into the events which played a role in the teachers' perceived shifts in their knowledge for teaching. Ten high performing experienced teachers were selected from 60 respondents to a validated TSKFT questionnaire on chemical bonding to take part in 90-minute long story-line interviews (Nilsson & van Driel, 2011). In the interviews teachers reflected retrospectively over their careers to identify and elaborate on significant events that played a role in the perceived shifts in TSKFT. Teachers also drew story-line graphs for each of the knowledge components (Student prior knowledge and conceptual teaching strategies under investigation here) to help them remember the influence of past events. A grounded analysis of the individual interview transcripts and story-line graphs preceded a cross-case analysis to identify significant events and shifts in teacher knowledge, and identify the trajectories for the group of teachers.

To answer the second question, the impact of a one-day workshop on content knowledge and PCK of teachers was investigated in a small-scale case study. Although we were aware that short interventions may have limited impact (Supovitz & Turner, 2000), we were persuaded that tightly focused content and the centrality of the topic to chemistry would contribute to positive impact, as teachers respond well to interventions that have potential to improve student learning outcomes (Guskey, 2002). Twenty-one teachers of varying experience and qualifications attended a one day interactive workshop on aspects of teaching and learning chemical bonding.

As a pre-test, participants answered a previously validated instrument comprising 25 four response multiple-choice questions testing their understanding of chemical bonding concepts. During the workshop they were exposed to research findings on learners' misconceptions about aspects of chemical bonding and provided with opportunities to plan and deliver mini-lessons focused on addressing these. Participants answered the same knowledge test instrument after the workshop. Three months later nine teachers answered Toerien's TSKFT questionnaire (Toerien, 2017). In the intervening period, part of this group had taught chemical bonding to their students in schools. The knowledge tests were analysed using traditional item analysis such as facility percentages and the TSKFT test was analysed using a validated rubric.

To answer the third research question, on the impact of a change in the curriculum, and the accompanying introduction of new curriculum documents on the sequence in which chemical bonding was taught, 227 physical science teachers answered a survey in which they were asked about their approach to sequencing topics in chemical bonding. From this group, 11 experienced physical science teachers were interviewed. In the interviews teachers were asked for details on their teaching approaches and planning, particularly the strategies they use to ensure understanding of chemical bonding by learners. The interviews were analysed using the Model of Education Reconstruction (Komorek & Duit, 2004).

RESULTS

In response to the first research question, one of the ten cases, Doreen's, is presented below to illustrate the findings.

Doreen had 16 years' teaching experience. She graduated with a bachelor's degree in botany and zoology. Although she wanted to become a biology teacher, she accepted a post teaching chemistry and physics. Her teaching strategy at the beginning of her career was influenced by the opinions of her more experienced colleagues at the school which were strongly textbook bound. 'I was scared that if I missed a word from the textbook, they [the students] would fail. ... In our school there was very little emphasis on prior knowledge, so you would have to just start pumping them full of information.' Over time, as she gained teaching experience, she was able to shift her attention to what her students were saying. She indicates this as 'learners' answ[ers]' in her story-line in Figure 2.

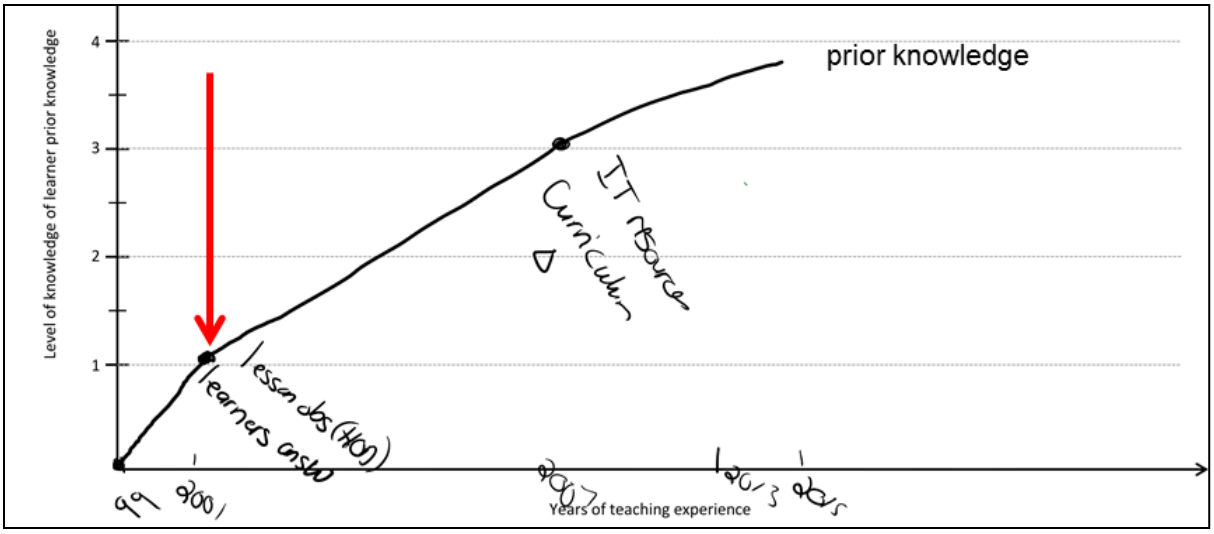

Figure 2. Doreen's story-line of her perceived shifts in knowledge of student prior knowledge

Post-graduate studies in education later in her career increased her knowledge about how students learn and provided her with knowledge about topic specific misconceptions to interpret her students' 'incorrect' answers. She reflects on this as follows: 'And only recently I know that an answer is not just correct or incorrect. If it is incorrect, there is a reason why it is not there …there is something causing that reasoning of the child to think that he is right'. The feedback from students and further studies later in her career increased her knowledge of students' ideas, which she could incorporate into her teaching strategies by moving away from the textbook, and becoming more student-focussed.

As a result of the frequent curriculum changes in South Africa, Doreen had the opportunity to attend curriculum training workshops. The workshops challenged her knowledge of curricula and supported the move away from textbooks to developing her own teaching sequence: '...because I knew the content, and I was confident… I don't teach from the textbook at all anymore. I am teaching a section that I know I am supposed to be teaching for the day, and I teach it with a structure that I consciously planned to teach'. Doreen indicated this event as 'curriculum change' on the story-line in Figure 2.

Analysis of Doreen and the other teacher's experiences identified three prominent themes or events which they perceived to have had significant influence on their knowledge for teaching - the influence of professional development activities, changes in the curriculum, and teaching experience. This led to the studies for research questions 2 and 3.

To answer the second research question regarding the professional development workshop, the diagnostic pre- and post-tests were analysed by calculating overall scores, averages and standard deviations, as well as teacher performance on each item. Results showed improvement in the test score average from 60% (pre-test) to 88% (post-test) with a stable standard deviation. Facility indices on specific questions ranged from 16% to 95% (pre-test) and 52% to 100% (post-test). Improvements in correct responses of greater than 50% on individual questions were observed for six questions. For example, Figure 3 shows responses to question 11: "Why do atoms form bonds?", a fundamental concept in chemical bonding. A shift towards the correct response of 64% was observed. The correct response is shown using an asterisk.

Question 15 ("What happens in the jar?") showed the poorest performance, generating a negative change between pre- and post-test. Nevertheless, figure 4 shows that a majority of teachers provided the correct response pre- and post-test. However, post-test an appreciable number gave the incorrect response D and some shifted from the correct response B to A. Responses show that some teachers retain the notion that sodium chloride comprises molecules, a misconception documented by Taber (2002) despite the fact that this was dealt with in the workshop.

11. Why do atoms form bonds?

A. This is what they want to do

B. Forming bonds makes atoms more stable

C.* Forming bonds is energetically favoured

D. Atoms are happiest with full shells of electrons

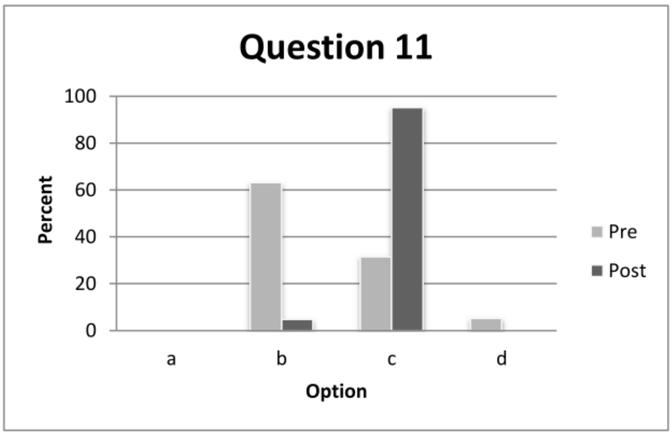

Figure 3: Pre- and post-workshop distribution of responses to "Why do atoms form bonds?"

15. Hot sodium reacts violently with chlorine gas in a gas jar. An exothermic reaction occurs that spatters sodium chloride on the sides of the jar. Which description best fits what happens in the jar?

A. Sodium chloride molecules form by electron sharing between sodium and chlorine atoms

*B. An ionic lattice forms from sodium and chloride ions

C. A giant covalent lattice of sodium chloride forms

D. Sodium and chloride ions form by electron transfer which bond to make sodium chloride molecules

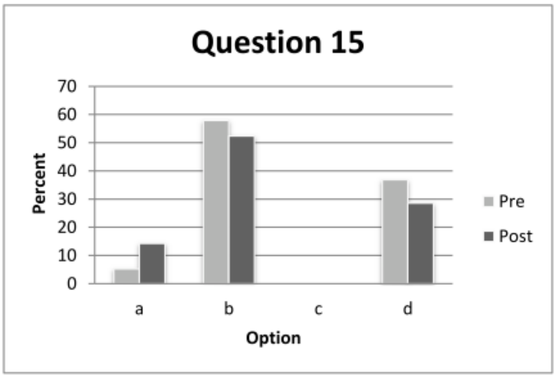

Figure 4: Pre- and post-workshop responses to "What happens in the jar?"

TSKFT data for the 9 teachers were analysed using a rubric to obtain competence, and identifying explanatory frameworks used by participants to describe chemical bonding in different contexts (Taber, 2002). The items were scored using a previously validated rubric on a four point scale of 1 (limited), 2 (basic), 3 (developing) and 4 (exemplary). The CK portion of this delayed test was scored using a validated memo.

CK scores of seven of the nine teachers ranged between 58% and 98%. Two scored below 50, one (28% and 48% respectively). The latter had evidently not engaged with the questionnaire providing only one or two word answers where explanations were required. The former, a masters' student with a poor CK background and no teaching experience showed contradictory knowledge of concepts emphasised in the workshop. This teacher had scored 93% in the multiple-choice post-test, suggesting that learning from the workshop was superficial and short-lived. The delayed test required explanations, rather than multiple choice answers. Of the other seven participants, five were practising teachers who had just completed teaching chemical bonding. The two remaining respondents were faculty members in physics and physics education, both with previous exposure to undergraduate chemistry.

The TSKFT test generated an overall score of 3, grading most group members as "developing". Three teachers scored at the basic level and one at exemplary TSKFT. The two components emphasised in the workshop, learner knowledge and conceptual teaching strategies, scored consistently at 3 (developing). Qualitative analysis of responses showed a move towards more sophisticated explanatory frameworks, for example, from an "octet" type to adopting a "minimum energy" principle.

The findings on the third question, regarding sequencing patterns for teaching chemical bonding, were obtained by comparing teaching sequences analysed from various sources – survey and interview data from teachers, curriculum documents and prescribed textbook. The learning sequences obtained from different data sources are given in Table 1.

Table 1. Patterns of chemical bonding learning sequences from survey, policy documents and textbook

Sequence identified in the survey and interviews	Sequence identified in curriculum document	Sequence identified from prescribed textbook
Attraction forces	Attraction forces	Attraction forces
Covalent bonding	Types of bonding	Metallic bonding
Ionic bonding		Lewis notation
Lewis notation	Lewis notation	Covalent bonding
Metallic bonding	Metallic bonding	Ionic bonding
Molecular shapes	Molecular shapes	Molecular shapes

From Table 1 it is clear that the curriculum policy document is not explicit on a learning sequence of topics for chemical bonding. This may indicate either that sequencing is not viewed as critical by policy makers, or that there is further need to refine the policy instruments whose ostensible premise is to support a constructivist approach (Department of Education, 2006). The analysis showed that there are differences between the chemical bonding sequences suggested by teachers to the one vaguely proposed in the curriculum policy document. Based on these findings, it is therefore recommended that an appropriate teaching sequence for chemical bonding should be included in policy documents.

In the interviews, the 11 teachers did not agree on a single learning sequence for chemical bonding. For example, four teachers re-organised the content sequence in a similar way to that suggested in the survey, starting with attraction forces, covalent bonding, Lewis notation, ionic bonding, metallic bonding, and molecular shapes. Two teachers mentioned using chalk and talk approaches and a further teacher focused on using prior knowledge to make science accessible to learners.

Eight teachers referred to chemical bonding as a problematic topic, because it is too abstract and difficult for learners to understand and three teachers spoke about the importance of prior knowledge during teaching and learning of chemical bonding and how prior knowledge facilitates learners' understanding of the topic.

The analysis of interview results indicate that the majority of the interviewed teachers think broadly about science content to be taught and restructure the science content before planning a learning sequence. The teachers also think about issues that might hinder learning of the topic by the learners thus showing the use of two components from the Model of Educational Reconstruction (Komorek & Duit, 2004). Despite, the fact that the majority of the teachers planned learning sequences that were in line with the framework, there were some teachers who failed to include the issues of learners' preconceptions about chemical bonding at the planning phase.

DISCUSSION AND CONCLUSIONS

In the space available, it has only been possible to give an account of one of the ten teachers interviewed and their trajectories overall. The case of Doreen illustrates her learning trajectory, also found in other teachers that teachers shifted from teacher-focussed towards student-focussed teaching approaches.

A combination of events, over an extended period of time, played a role in Doreen's perceived shifts in her knowledge for teaching. Early in her career, Doreen gained confidence in what she knew about the subject by teaching the same content year after year. She could then shift her attention to her students, realising that they had prior knowledge which could give her insight into how her learners understood the content. Later in her career, post-graduate studies in education gave her knowledge about how students learn and their alternative conceptions they may have. She was then able to incorporate this new knowledge into her teaching, shifting her teaching strategies to become much more student-focussed, and interpreting her students' 'incorrect' answers as tools to guide her teaching, and help her students understand better.

The link between awareness of student thinking and teaching strategies is evident in the second part of research addressed by the second research question and has also been highlighted as an important quality indicator by several researchers (e.g. Jin, Shin, Johnson, Kim, & Anderson, 2015). The workshop on chemical bonding offered to teachers targeted the link between these components. Teachers with sufficient teaching experience would benefit optimally from the workshop, particularly if they had the opportunity to teach the topic immediately after the workshop, which was the case for five of the nine teachers who provide additional data.

The findings reveal that the strategies utilised in the workshop impacted positively on teachers' knowledge and misconceptions of chemical bonding. The CK scores of the nine teachers who returned the three-month delayed post-test questionnaire demonstrated a moderately successful long term impact of the workshop on content knowledge. In terms of their knowledge for teaching, the two components emphasised in the workshop showed moderately good scores, with a majority of teachers at the "developing" level. Overall the study shows that if focused on a well-defined topic, one day workshops can have a medium impact on teacher knowledge.

The study of sequencing patterns revealed that the general idea for teaching chemical bonding is first to teach attraction force then types of bonding starting with covalent bonds followed by Lewis notation/theory and lastly, molecular shapes. The findings of the study are represented in a similar manner to what Levy Nahum, et al. (2008) term the "bottom up framework". Data showed that teachers were clear on which concepts for teaching chemical bonding should be at the beginning of the sequence. Their ideas imply that when teaching chemical bonding the concept of covalent bonding should be introduced first, in contrast with the suggestion of Taber and Coll (2003) who felt that ionic bonding should the taught at the beginning of the sequence but in line with the argument proposed by Dhindsa and Treagust (2014) to start with covalent bonding.

This paper has tried to provide illustrative research to amplify teacher learning trajectory identified in question 1. The two game changing events identified by Doreen - awareness of student thinking and an understanding of curricular issues including sequencing we played out in the research related to questions 2 and 3. Teachers did benefit from the short workshop, but learnt more if they taught the topic soon afterward, and teachers' ideas about sequencing topics in chemical bonding are influenced mainly by their perceived structure of the content and their knowledge of student thinking.

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MECHANICS PROGRAMMES UNDER THE JAPANESE INSTRUCTION THEORY HEC

Koji Tsukamoto
Chiba Institute of Science, Choshi, Japan

Around 1950, Dr. Kiyonobu Itakura of the Japanese National Institute for Education, a historian of science and educator, conducted a study of Japanese students' understanding of scientific knowledge, concluding that they clung to intuitive concepts acquired through their daily experience. To overcome these intuitive concepts, Itakura advocated Kasetsu Jikken Jugyo*, or Hypothesis Experiment Class (HEC) in English, in 1963. The lesson plan 'Spring and Force', developed and published in the early days of Itakura's work, remains highly effective at teaching statics in schools, even today.*

Keywords: mechanics, conceptual understanding, learning theory

INTRODUCTION

In 1963, Dr. Kiyonobu Itakura (a senior scientist emeritus at the Japanese National Institution for Education) advocated a instruction theory called the Hypothesis Experiment Class (HEC) based on his study of the history of science and scientific epistemology (Itakura, 1963). Over 50 lesson plans, termed *Jugyosho* (H-E Classbook in English, or Classbook for short) that created enjoyable science classes were published. These plans cover a wide range of fields, from biology to mathematics, even to social science.

Although the concept of HEC is acknowledged in Japan as a fruitful achievement, it is little known outside the country since its basic literature has not been published abroad in any foreign languages. In this paper, we will introduce an outline of the Classbook for 'Spring and Force', which was Itakura's initial representative work and an achievement of Itakura's thesis.

COGNITIVE RESEARCH AND HEC

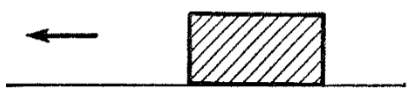
Around 1960, Itakura published the results of his study of students' understanding of scientific knowledge, based on his prediction that the confusion about scientific knowledge conception in the history of science would also be seen in the confusion of students in science class (Itakura, 1964; Itakura & Kubo, 1965; Iwaki, Kamikawa, & Itakura, 1959). A sample of the research done by Itakura is shown below (Figures 1 and 2).

[Problem 1] (Target: 93 students in a public school, 13 years old) If this were a smooth table, and air resistance and friction were vanishingly small, sliding the block will lead to which of these results?

(i) The block will run to the end of the earth.

(ii) The block will stop after a little because of its weight.

(iii) The block will stop for another reason.



N	1	0	1
i	14	14	28
ii	27	24	51
iii**	4	9	13

Figure 1. Problem 1 with results

[Problem 2] (Target: 77 students in a private high school, 16 years old)

A disk is moving horizontally on ice.

i. Indicate all forces acting on the disk.

ii. Indicate these force on the figure.

(In all, 39/77 students placed an arrow pointing ahead)

iii. How much distance will the disk go if its initial speed is 2.8 m/sec and the coefficient of kinetic friction is 0.02.

(Correct answers were given by 10 students; 8 answered correctly on all questions)

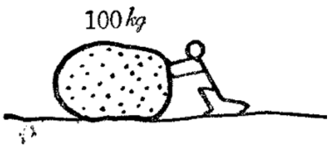
Figure 2. Problem 2 with results

After realising that even privileged private-school students could not answer these problems correctly, Itakura characterised students as believing in medieval impetus or vis impressa mechanics.

He published his results on research into frictional force (Figure 3).

[Problem 3] (Target: 93 students at a public school, 13 years old)

There is a stone of about 100 kg. If there is friction, how much force is needed to move this stone horizontally.



i. 100 kgw.

ii An equal amount to the frictional force.

iii The frictional force + 100 kgw.

iv. The frictional force or 100 kgw (whichever is larger).

v. More than 100 kgw.

vi More than the frictional force.

viii. More than the frictional force + 100 kgw.

ix. Impossible to answer from this information alone.

	Number of Answers		
	A (46)	B (47)	(93)
N*	0	0	0
i	0	1	1
ii	1	1	2
iii	27	15	42
iv	0	3	3
v	2	5	7
vi	1	2	3
vii	13	18	31
viii	1	1	2
ix	1	1	2

* N means blank.

Figure 3. Problem 3 and results – (Frictional Force)

Most students (45%) thought that friction + 100 kgw or more is needed to move the block. Itakura noted that this result is similar to Bradwardine and Buridan's mechanics from the mid-fourteenth century. Though Buridan accepted inertia, he thought that the force applied needed to be greater than the weight of the object which was being moved.

He also published his results on statics (Figure 4).

[Problem 4] (Target: 93 students in a public school, 13 years old)

There is a metal bottle with a vacuum inside. When hydrogen is put in this bottle, the weight of the bottle is

i. lighter than the bottle with the vacuum.

ii. heavier than the bottle with the vacuum.

iii. the same weight.

iv. dependant on the weight of hydrogen put into bottle.

N	0	1	1
i	19	18	37
ii	10	14	24
iii	8	9	17
iv	9	5	14

Figure 4. Problem 4 and results – (Statics)

For this problem, 40% students answered i (It is lighter than vacuum bottle), an answer consistent with Aristotelian mechanics.

From his research, Itakura concluded that the students' common or intuitive concepts sometimes prevented them from understanding scientific concepts.

STRUCTURE OF HEC

Basic idea of HEC

To overcome students' intuitive concepts and bring them to a true understanding of science, Itakura began advocating HEC in 1963 (Itakura, 1963). Itakura stated that to overcome students' concrete intuitive concepts, the conflict between scientific logic and common intuitive logic must be made clear, so that students realize the superiority of scientific logic and concepts (Itakura, 1967).

Classbook

The fundamental concept of HEC is that 'all preparation should be supported, so that any teachers who is not master or veteran but is eager to perform good instruction can achieve their goal'. To realise this, Classbooks, which have the multiple functions of instruction manual, textbook, and notebook, are prepared. Using a Classbook, anyone have good lessons.

Evaluation of the class

The goals of HEC are as follows (Itakura, 1966).

1. The concepts and laws taught in the Classbook will be mastered by the students.

2. All students will enjoy science and their lessons.

To evaluate the first goal, the average score on the final test should be 90%. To achieve the latter goal, more than half of students will respond to a questionnaire that they like science or the HEC lesson, if the questionnaire is conducted after an HEC lesson, and none (except for two or three anomalous students) would answer that they dislike it.

Procedure of HEC

A Classbook is composed of a series of problems and readings. In the 'problem', all students or pupils must expect a certain result and see their expectation was right. The problem consists of four steps: problem statement, expectation, discussion, and experiment (Itakura, 1967).

In the problem statement, all procedures for conducting the experiment are given. The teacher sets up the experiment as instructed in the statement and explains it to the students. When students understand what is being asked, they choose their expectations of the result of experiment.

The expectation should be chosen from multiple given options. At the beginning of the lesson, the students may choose their expectation based on their intuition without any specific reason, as they have not studied the subject yet.

The teacher requests the students to raise their hands for the option they choose, counts how many students have chosen the option, and writes the numbers up on the board. The teacher asks the students why they have chosen their option. An open discussion should be conducted if needed. After asking the students if anyone wants to change his or her expectation, the teacher conducts the experiment.

The teacher should confirm what option is correct, not explaining why this result occurred and goes on to the next problem. Since people often interpret experimental result to favour themselves, teacher should not explain until the students have acquired a true understanding of scientific concepts. A number of experiments is needed to teach each law or concept in the HEC.

When almost all students have acquired a scientific law or concept, the law or concept is explained in detail through the reading in the Classbook, which often contains the episode within the history of science.

All of this occurs in the Classbooks.

THE CLASSBOOK 'SPRING AND FORCE'

'Spring and Force'

Over 50 Classbooks have been published; these cover not only physics and chemistry but also social science. We introduce the classical Classbook 'Spring and Force' which aim to teach statics published in 1967 (Itakra, 1967).

As has been mentioned, Classbooks contain a number of problems and readings. The one for 'Spring and Force' consists of almost 40 problems and readings and is over 60 pages long. For this reason, we cannot describe all of it here, only being able to introduce it briefly.

Aim of 'Spring and Force'

'Spring and Force' teaches the static concept of force. The intuitive concept of force acquired in daily experiences is based on the sense of human force and ad hoc reasoning. However, the scientific concept of force is based on coherent logic. Using various experiments, to create a conflict between the intuitive concept of force and the scientific concept is the aim of this Classbook.

Introduction of the concept of force

Usually, the concept of force is introduced by gravitational force since almost all students today know gravitational force. However, although people are able to understand the concept of force through understanding an equilibrium of forces, it is difficult to teach equilibrium with gravitational force. The force of the human relates to the feeling of exhaustion and tension, so normal force is difficult to understand.

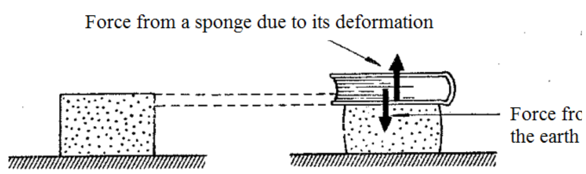
This Classbook introduce the concept of force using the equilibrium of gravitational and magnetic forces.

Introducing normal force by using spring model of matter

After introducing the concept of force, normal force is introduced through the idea that all matter has the nature of a spring.

Since normal forces are often logically introduced through the formal balance of forces, students tend to think that mechanics is a system of sophistry. Even if students can answer correctly on a paper test, they do not believe it in their minds. To render the concept comprehensible, normal force is introduced using a model of matter as a spring. To make this idea concrete, students are instructed that even very strong springs will be deformed by a little force and that a deformed sponge under a book will produce force due to its deformation, as described in this Classbook. (Figure 5a).

The fact that even a desk will be deformed by a small force, since it is composed of atoms, is described in the reading. Students thus realize the concept of normal force themselves (Figure 5b).



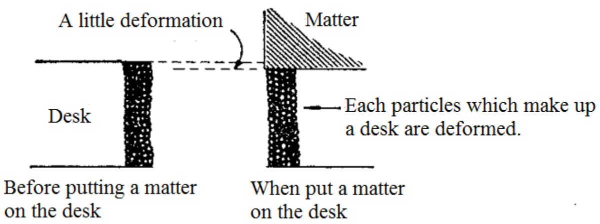
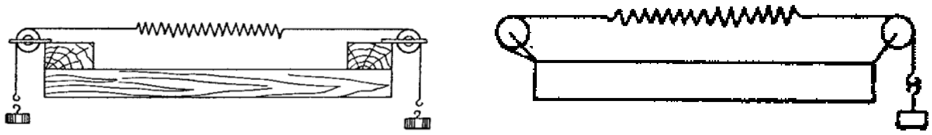


Figure 5a. A book on the sponge **Figure 5b Deformation of the desk**

Experimental conflict between the scientific principle and the intuitive idea

Students accept scientific concepts through problems that lead to conflict between the intuitive idea and scientific logic. One of these problems presented in this Classbook is given in Figure 6.

[Problem] A spring is extended by two weights hanging on both of its sides. If we fix one side of the spring and hang a weight on the other side, how far will it be extended?



i. half the length

ii. the same length

iii. double the length

Figure 6. Classbook Problem - Spring extended by two weights or a weight.

In this problem, most students choose i. Since the weights are reduced by half, it is natural to expect that the length of the extension of the spring will also be half. However, the result of this experiment gives ii. Using such experiments whose results dramatically conflict with intuitive concepts, students can learn the effectiveness of the logic of science over intuitive ideas.

EVALUATION

Result of the final test

As noted, the Classbook under discussion consists of a number of problems. We have only briefly introduced part of it. To go through the whole of this Classbook, 12–13 class hours are needed (a class hour is 45 minutes). According to Itakura's thesis, a final test, made by another researcher, which was used to evaluate their (another researcher's) lessons was used. In the researcher's report, the average of the final test for students taught by their lessons was 46/100. However, the averages on the final test after the HEC lessons was 87–97/100 (Itakura, 1967).

Students' motivation

In HEC, the result of questionnaire determining whether the class was enjoyable was given more value than the results of the final test. Even if the students acquired correct scientific knowledge, this would be meaningless if they did not enjoy learning. The students were thus asked for their evaluation of their degree of enjoyment of the class.

Degree of enjoyment

5. Very enjoyable

4. Enjoyable

3. Neither enjoyable or not.

2. Boring

1. Very boring.

If over a half of students answer 4 or 5, and few answer 2 or 1, the lessons are judged to have succeeded. For Itakura's work in 1967, over 90% of students chose 5 or 4 (Itakura, 1967).

CONCLUSION

We have briefly introduced the basic theory for HEC and the classical Classbook 'Spring and Force', developed in the early days of Itakura's research. Cognitive study of scientific knowledge has been conducted systematically around the world, beginning in the 1980s. Lessons have been improved using this cognitive research. Some of the results are similar to HEC.

However, one special feature of HEC remains the concept of the Classbook. The theory of HEC is little known outside of Japan, because the basic literature for HEC has not been translated into English.

Our colleague is preparing to publish an English translation of Itakura's thesis this year. We expect that HEC will attract attention outside of Japan.

New Classbook that introduce dynamics are in development. We hope to present these it in the future.

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FINDING THE 'RHYTHM' IN A SCIENCE CLASSROOM: ANALYSING TEACHER'S SPATIAL POSITIONS AND THE INTERACTION DURING TRANSITIONS

Miranda Rocksén
University of Gothenburg, Gothenburg, Sweden,

In this presentation, the contributions and constraints from a methodology based in dialogical theories of communication, is illustrated and discussed. The purpose of the study is to investigate the details of how a discursively changing environment is achieved in a science classroom. The approach was enabled by investigating video data from a sequence of 11 lessons about evolution in a grade 9 (15 years) in which a suitable pattern of activity, alternating between small group and whole-class activities, was established. Using data from four simultaneous cameras, the analysis focused on teacher movements and spatial positions in the classroom and how the interaction between the teacher and the students was sequentially organised. The results show how during transitions between activities the teacher used a set of signals such as repeating the question and backing away from the students, in the communication. The students responded to these signals by shifting their focus of attention resulting in a coordinated classroom communication with smooth transitions between whole-class and small-group activities. The described details of the interaction and the sequential organisation provided by the study illustrate some of the main contributions from using the methodology. The focus on the embodied communication evokes constrains with regard to developing aspects of the subject matter being taught and learnt. Also, this methodological approach does not support conclusions about teaching effectiveness. Further research focusing on classroom activities is needed in order to show empirical examples from different settings and develop the understanding of how activity patterns are interactively achieved.

Keywords: classroom discourse, video analysis, science education

INTRODUCTION

"In a nutshell, how helpful is it for a science teacher and students to be exposed to the genre of scientific argumentation, when their normal, daily lessons are based on a routine of teacher presentation? Our view is that the priority must be, first of all, to make these existing practices more 'visible', and then to point towards how they might be extended by employing the different kinds of interactions we discuss." (Mortimer & Scott, 2003, p 5)

I will in the presentation illustrate and discuss contributions and constrains from a methodology based on a case-study design and within a framework of dialogical theories of communication. This is a research approach that may contribute to make visible the practices of science classrooms for the benefit of researchers' and science educators' further investigations and development of that practices. The purpose of the current study is to investigate the details of how a discursively changing environment is achieved in a science classroom. In the title, I have chosen to define this as a 'rhythm', which consists of relations between two components, one spatial and one temporal. In science education, the nature of the interaction between teachers and students is emphasised as one critical aspect with the potential to significantly contribute to students' meaning making (Mortimer & Scott, 2003). Still, studies that approach the spatial and temporal aspects of science teaching practices and provide empirical examples of how this can be achieved in different settings, are rare. In this Introduction, I briefly present some examples from the field of education that expand on these two components as a background to the reader. The theoretical framework and some of the basic assumptions that are shared among dialogical approaches are then presented in the section Theory. In Methods, I describe the special interest for this particular study and provide some details about how data was generated and some ideas about what it might imply to use and work with this methodology in video-analytical studies. The Results summarizes the study results. Finally, in the Discussion, I consider some contributions and constrains from using the methodology.

Addressing questions of time and space

Teachers' gestures and movements have previously been investigated for example in studies influenced by the approach to proxemic behaviour (Hall, 1963, 1969). Hall investigated for example the use of space in public and in private and between different cultures. This approach to the study of gestures and movements in social interaction seeks to establish meanings, and is based on the assumption that there is the possibility to assign certain meanings to bodily movements and behaviour.

Lim, O'Halloran, and Podlasov (2012) investigates two teachers' moves in front of their respective classes. The traces from the individual teacher's movements show characteristic patterns in how each individual use the classroom space during a lesson. In one of their empirical studies, Sensevy, Gruson and Forest (2015) investigates one teacher's interaction with children sitting in a small-group around a table learning a memory game. Here, the teacher's gestures are seen as partly contributing to how the didactical contract is maintained in the interaction.

Studies have also investigated gestures (Arnold, 2012; Rosborough, 2016) and the performance of science concepts during lectures (Pozzer-Ardenghi & Roth, 2007). To different degrees, all these approaches take into account spatiality, in terms of types of embodiment, as well as temporality. However, several authors have asked for further investigations into the temporal aspects of teaching and learning (e.g Mercer, 2008; Roth, Tobin, & Ritchie, 2008).

Alhadeff-Jones (Alhadeff-Jones, 2017) presents a review of the study of time and theorizes about time in educational research. In this book physics and biology exemplify contrasting disciplinary conceptions of time that are reflected in conceptualisations of time in education. In physics time is more linear while in Biology time is more circular and emergent. Rhythm characterises the relationships between changes: "Rhythms refer to the specific way we perceive the signals (e.g.,visual or auditory) and signs (e.g.,language) characterising the experience of time" (Alhadeff-Jones, 2017). Two studies that shares the focus on the relation between the use of space in relation to aspects of time, in particular the role of interaction during shifts between classroom activities, are (Icbay, 2011) and (Jacknick, 2011). Icbay (2011) applies the concept of tying signals and investigates the restoring of classroom order after transitions. Jacknick (2011) investigates teacher initiated shifts between activities and the interactional work required of students to challenge such shifts. The present approach investigates the embodied aspects of science teaching, such as physical positions, gestures and gaze in the interaction with students.

THEORY

The study is based in dialogical theories of communication (Bakhtin, 1986; Linell, 1998, 2009). One possible characterisation of some of the approaches based on the framework – is as studies of naturally occurring data that produces results in the form of detailed descriptions of empirical cases. Shared among dialogical approaches is the assumption that human action, communication and mind remain reflexive, intersubjective and context-dependent. Also, the elaborated view on spoken language and social interaction embraced by the framework facilitates the analysis of video-data from classrooms. Emphasised in this view is the sequential production of utterances, that spoken language is embodied and that linguistic resources – for example words and subject-specific terms – have meaning potentials and that meaning is jointly constructed. These ways in which the nature of spoken language differs radically from the nature of written language, are significant to verbal communication in different contexts.

The analysis is developed based on the assumptions about the dialogical nature of human action, communication and mind. The purpose here is to investigate the details of how a shifting environment is interactively achieved in a science classroom. Focusing a shifting pattern of activity, established by a previous study (Rocksén, 2017), this study seeks to answer the following questions: How is the shifting pattern of activity sequentially organised? What significant gestures and moves can be identified in the teacher's interaction with the students during the transitions between small-group and whole-class activities? What are students' responses?

METHOD

The particular case under investigation is the teaching of a unit in biology in grade 9 (15 years) in a particular classroom where an established shifting activity pattern was described by an earlier study (Rocksén, 2017). According to Yin (2009), case-study may be a particularly feasible design in the work of defining boundaries between a phenomenon and how this appears in the real world. Further, Silverman (2010) describes how case studies identify these boundaries, define the unit of analysis, delimit a research problem that focuses on some features of the case, and still preserve the "integrity of the case" (Silverman, 2010, p. 138). The project developed an application for vetting of ethics and the teacher and students gave their informed consent to participate. The particular data set was re-used for this study . It included 38 hours of video covering 11 lessons. Each lesson lasted 50 minutes and was planned and conducted by the teacher.

Four simultaneous cameras were used for the recordings (Clarke, Mitchell, & Bowman, 2009). Two of the cameras provided close-ups on two different student groups, one camera followed the teacher and one camera provided an overview of the classroom. The data was stored on a separate server and retrieved through Transana multiuser software. Transcripts in combination with time-based coding were used in order to capture, investigate and analyze the details of the transitions between activities. Transcripts of speech as well as visual conduct, emphases and overlapping speech were developed for the selected episodes and included frames from the video (see Heath, Hindmarsh, & Luff, 2010). The transcripts were iteratively revised by returning and repeatedly looking at the video, and became key data (Derry et al., 2010, p. 20).

The methods for analysis involved an iterative process of repeated watching of the video – developing transcriptions, identifying sequences that were found relevant to the specific focus of interest. Then building a collection of sequences, developing more detailed transcriptions, using the theory and theoretical concepts within the framework in order to understand the unfolding of particular events.

In a process of analytical induction (Erickson, 2012) the physical positions, gestures and gaze in the interaction between teacher and students were established and documented. The focus of interest was the transitions between different activities, and how the shifting pattern of activity is constituted, in an attempt to reveal what cues the teacher provides to the students and what the nature of any irregularities to that pattern mean in the interaction. In order to do this, the phases of transitions between activities were focused: transitions from whole-class to small-group activity, and transitions from small-group to whole-class activities. During the final lesson, there are three small-group activities, and in particular this caught my interest. The next step was to study these phases of transition. The final part implied to identify and represent the results in text, and text combined with frames from the video – including excerpts showing the details of empirical data. The next section includes a summary of the results.

RESULTS

The results show the details of the classroom interaction during transitions between whole-class and small-group activities along the eleven lessons. A sequential organization could be described in detail including phases of transition before and after the small-group activities. The introduction and ending of small-group activities are indicated by the teacher's different physical positions in the classroom and shifts in the students' attention.

One example of how a small-group was initiated is when the teacher picks up on a contribution previously made by one student talking about sun radiation causing spots in the skin. The teacher asks:

"*but okay do you think, do you think that such mutations in a small, let's say a mutation happens in a muscle cell, will this be transferred to your kids? Think about this now. Talk with the person next to you. I do not just want a finished answer at this point*."

A few seconds later, the teacher leaves the front of the classroom and the students shift their focus of attention, Figure 1.

This particular introduction represents about 20 seconds; however this single example represents a recurring situation in the classroom. Like in the example, during the transitions, the teacher in this particular classroom asks questions for the students to discuss standing in the front position but the time and exact formulation of the question is a consequence from the interaction with the students happening immediately before this moment.

The teacher's use of a set of tying signals to which the students respond by shifting their focus of attention. Identified tying signals are: *Instant reformulation of contribution in whole-class,* *Repeating the question*, *Gestures highlighting concepts noted on the white-board*, *Gestures requesting response.* When shifting back to whole-class activity this transition is faster: *Nomination of students*, *Loud voice*, *Re-taking classroom front-position*, with body and gaze oriented towards nominated students. Students shifting focus of attention is shown in their *body position*, *talking without raising their hands*. This did not only occur in small-groups but also across groups getting ideas, some more vividely, some more silent and not as focused. This phase is also characterised by the more informal character of talk about the issue at hand with the teacher when she approaches.

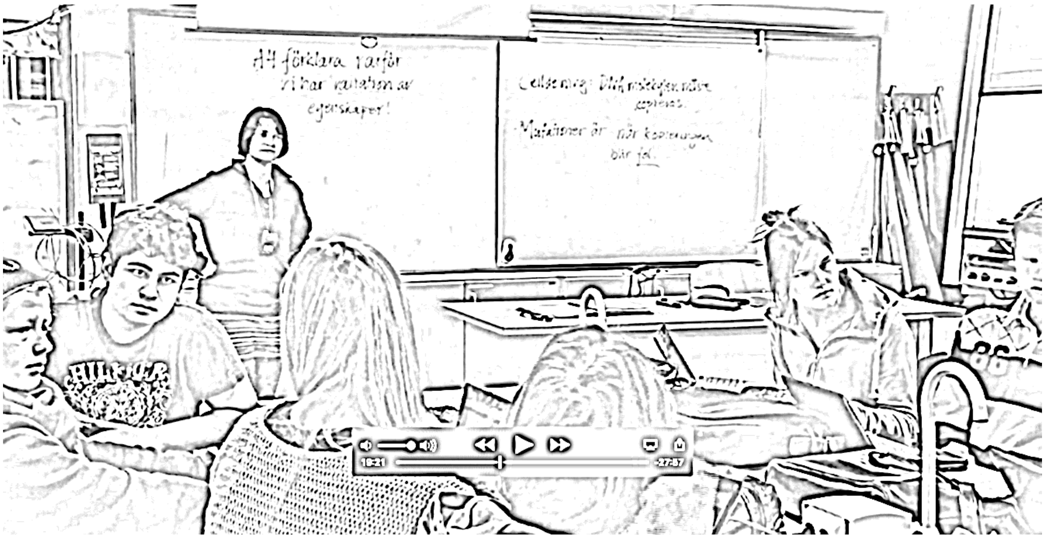

Figure 1. The teacher has left the front of the classroom.

In the introduction of the third small-group activity a discrepant instance is identified. Here, the transition is delayed and teacher re-starts using the tying signals a bit differently. In this particular situation, the question is not timely repeated. When students do not respond by shifting their focus of attention, the teacher reformulates and writes down the question on the white-board and then students turn to each other to discuss the assigned task.

DISCUSSION AND CONCLUSION

The study was facilitated by the quality of the video-data and the already established pattern of activity. One general conclusion based on the study results is that during phases of transition a joint attention to the topic involves gaze, facial expression, gesture and physical position. The study shows that movements, gestures and voice is associated with shifting physical positions. For science education *a discursively changing environment* implies particular teacher challenges. For example, it requires flexibility in the communication with students with timely reformulations of contributions made in whole-class. In the investigated classroom, the repeating of a well-defined question was critical.

Descriptive case-studies are not useful for answering every question. They may however respond to the question of how teachers and students interact in a science classroom and therefore contribute important understandings of the challenges involved. Single-case studies also benefit from systematic and high quality approaches to the collection of data. This would be a reason for shared principles and quality criteria for video-analytical studies could be further developed by researchers in the field.

Illustrated in this study is a methodological approach based on video-analysis of the interaction in classrooms. The study displays detailed patterns in the classroom ecology of action (Erickson, 2012) of how one teacher and a group of students coordinate their interaction into a shifting environment where small-group activities are embedded in whole-class teaching on a regular basis.

The theoretical framework embraces a view on interaction as embodied and involving several temporalities, which enables the analysis to include embodied aspects of the communication in the classroom. Altogether the theoretical framework is found suitable for analysing video due to the elaborated view on spoken language and social interaction.

One of the constraints of the dialogic and interactive approach to teaching and learning in general is that content may be downplayed (Ongstad, 2004). The focus on gestures and moves may take the attention from the scientific concepts in focus. The content is embedded in the interaction and requires specific analytical solutions, units of analysis etcetera.

This is not a type of research that prescribes best teaching practices, but a framework potentially useful for making comparisons across classrooms. Most of all the described methodology enables expanding conceptualisations of teaching and learning, new descriptive units, aspects of space and time, and is therefore promising.

The nature of the interaction between teachers and students is emphasised as one critical aspect with the potential to significantly contribute to students' meaning making in science. Although this highlights the benefits from developing a variation of discourse patterns in science classrooms few research studies show detailed examples from different settings. By illuminating the details of how this can be achieved in different settings research can provide the empirical base necessary for bringing discussions further in teaching practices and teacher education.

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SCIENCE INTEGRATED WITH AESTHETIC EXPRESSIONS FOR BETTER UNDERSTANDING OF SCIENCE SUBJECT MATTER

Ulrika Tobieson[1] *and Ann Mutvei*[2]
[1]Södertörn University, Department of Culture and Education, Huddinge, Sweden
[2]Södertörn university, School of Natural Sciences, Technology and Environmental Studies, Huddinge, Sweden

Teachers have to create a variation of learning situations to increase the understanding for theories and abstract models in science. We have experiences of combining aesthetic expression with science in pre-service teacher programme for more than ten years and have seen the benefits of embodying abstract theories with dance, art, music or drama and better understanding of science subject matter. The integration of science and aesthetic forms of expressions have support in the Swedish curriculum both for preschool and the compulsory school and it is therefore important to include exercises using aesthetic expression in the teacher education program. The purpose of the workshop was to give examples of how art can be used to study phenomena in science. The workshop was divided into three parts. In the first part the participants were doing different exercises embodying concepts in physics and creating relations with each other. In the second part the participants in groups constructed a kinetic mobile. In the third part, the participants reflected and discussed their experience and understanding of phenomena during the workshop. Examples of assessments of the construction process were presented. Here we also present the planning and theoretical background to the work with aesthetic expression of science.

Keywords: aesthetic expression, integrating art with science, learning outcome

INTRODUCTION

Every student is unique as well as every learning experience is particular in its own way and therefore is conducive to a joint future where our common agreements affect our habitual experience of the world. Martha Graham, innovator of modern contemporary dance expressed the concept of uniqueness and the ability to partake actively (Halprin, 2003);

There is vitality, a life force, an energy, a quickening, that is translated through you into action and because there is only one of you in all time, this expression is unique.

And if you block it, it will never exist through any other medium, and will be lost.

As a teacher it is crucial to have the opportunity to create a variation of learning situations in order to deepen, broaden and crystalize the understanding especially addressing complex phenomena and abstract concepts together with models and theories.

John Dewey pointed out the importance of achieving experience in order to acquire knowledge, a sort of "experience through learning" (Pugh & Girod, 2007) which can be understood as an embodied integrated knowledge received through active participation. In Canada *Learning through the arts* was created as a national educational program (Smithrim & Upitis, 2005). This program showed an evident increase both in student engagement in other subjects than art as well as a higher level of motivation in learning. Visual and performing arts called *Arts-*

Infused Learning has been found to be important for different subjects, besides art in school such as language, math, science, and history/social studies courses (Lorimer, 2011). It was shown that using art in order to understand complex phenomena in science increased student's concentration of the exercise as well as their understanding (Lorimer, 2011). It was also noted that *Arts-Infused Learning* encouraged intercultural collaborations and trans-disciplinary understanding. Music has also been described to successfully integrate other subject where young children in preschool could better understand the meaning of different concepts (Economidou Stavrou, et al., 2011). Education of artists together with pre-service teachers in teacher education also showed the advantages of integrating different professional disciplines as well as different disciplines in art together with the subject matters. These types of student collaboration increased their enthusiasm about teaching and it broaden their perspective on learning in and outside the classroom (Ketovuori, 2011).

SUPPORT IN CURRICULUM

In Sweden students in pre-school and compulsory should learn to express their knowledge in using art. In the curriculum of Swedish preschool this is expressed as

> *The work team should give children the opportunity to develop their ability to communicate, document and describe their impressions, experiences, ideas and thinking processes by means of words, concrete materials and pictures, as well as aesthetic and other forms of expression (Skolverket a, 2011, p. 11)*

Further, in the aims of the subject biology, physic and chemistry in the curriculum for compulsory school:

> *Teaching should contribute to pupils developing the ability to discuss, interpret and produce texts and various forms of aesthetic expressions with scientific content (Skolverket b, 2011, pp. 105, 120, 135).*

Therefore, it is important to include this type of activity as well as knowledge of the art itself to be able to use these tools to create a diversity of learning situations. This skill described in the Reporting Guidelines for

International Teaching Placement for professional development of teachers used during placement express:

Commands and uses various communicative abilities (for example, body language, drama, music, pictures).

EXPERIENCES FROM TEACHER EDUCATION

At Södertörn University the science teachers have worked together with artists in teacher education during the last 15 years with the purpose to create an education from a more diverse intercultural perspective. Disciplines of Art such as dance, art, drama and music have been used, e.g., to visualize hydrogen bonds between water molecules by dancing, forces and balance in producing kinetic mobiles, details of biological material by drawing, drama exercises showing the pump of blood and digestion and singing songs about the cycle of water creating clouds and rain.

In 2011 Södertörn University teacher education hired a group of artists in order to teach what was now mentioned as Aesthetic Learning Processes. Examples of aesthetic expressions in 2- and 3-dimensions in a science course for pre-service preschool teacher is shown in Figure 1. During the aesthetic exercise students recalled the content of the science course with examples like frictions from shoe soles on ice, insulation of a snow and the effect of gravity on a door hinge. They then created a world where night and day, planet system, seasons or the phases of moon also should be included (Figure 1).

Figure 1. Closing of workshop with artefacts created by pre-service preschool teacher students

After the course, two years later, the students were evaluating the course by answering questions like:

> Describe how Aesthetic learning processes have supported and/ or enhanced your understanding of different phenomenon, concepts and abstract models?

Here are a few randomly picked answers:

> "Through talking around the concepts and making a conclusion at the end of the session".
>
> "Through giving knowledge a different and new dimension".
>
> "Through the process and creative thinking outside the box during the art-making process I have gained a deeper understanding."
>
> "Go beyond the theories, express my thoughts not only through written text. I have learned to share my thoughts and to be openminded toward others"
>
> "Aesthetic learning processes have supported to transfer our theoretical knowledge into practical action"
>
> "I have understood the meaning of different concepts especially the difficult one. Practicing practical exercises that reveal what we are reading have developed my understanding of different areas. And learning each other's learning "

THEORETICAL BACKROUND TO THE STRUCTURE OF THE WORKSHOP

Intermodal theory – modalities of imagination

Joseph Beuys argued that “Everyone is an artist” and we all strive for coherence, connection and *Beauty* as we struggle to construct meaning, direction and shape our lives, in our habitual world experience. *Beauty* as the term is used in the understanding and the implementation of *Intermodal theory* refers to a distinct response to an artistic act and/or an artwork that stirs us and which we associate with *Beauty* (Knill, 2003). The response has a bodily origin, which sometimes describes as ‘moving’, ‘touching’ or ‘breath-taking’. Most languages suggest this sensory effect even if we do not always experience the effect literally. The notion of *Beauty* is closely linked to the phenomenon when a ‘quite-right’ image emerges as a felt sense, an image that matches and resonates with the psychic condition of the individual person or group working together on the shaping and constructing of knowledge inherent in the subject matter. This is followed by a shift in awareness often experienced and described as a sharpened understanding and change in the notion of time and the conception of the learning process. This shift is often linked to a shared ‘aha’ -moment or experience. The phenomenon occurs whether the experience of *Beauty* is intensely joyful and pleasurable or is characterised by pain, confusion and perplexity (Knill, et al., 2005). The contrary quality to an embodied *Aesthetic response* (Figure. 2 left) would not be the idea of ugliness but rather dullness and an apathetical inability to respond (Knill, 2003).

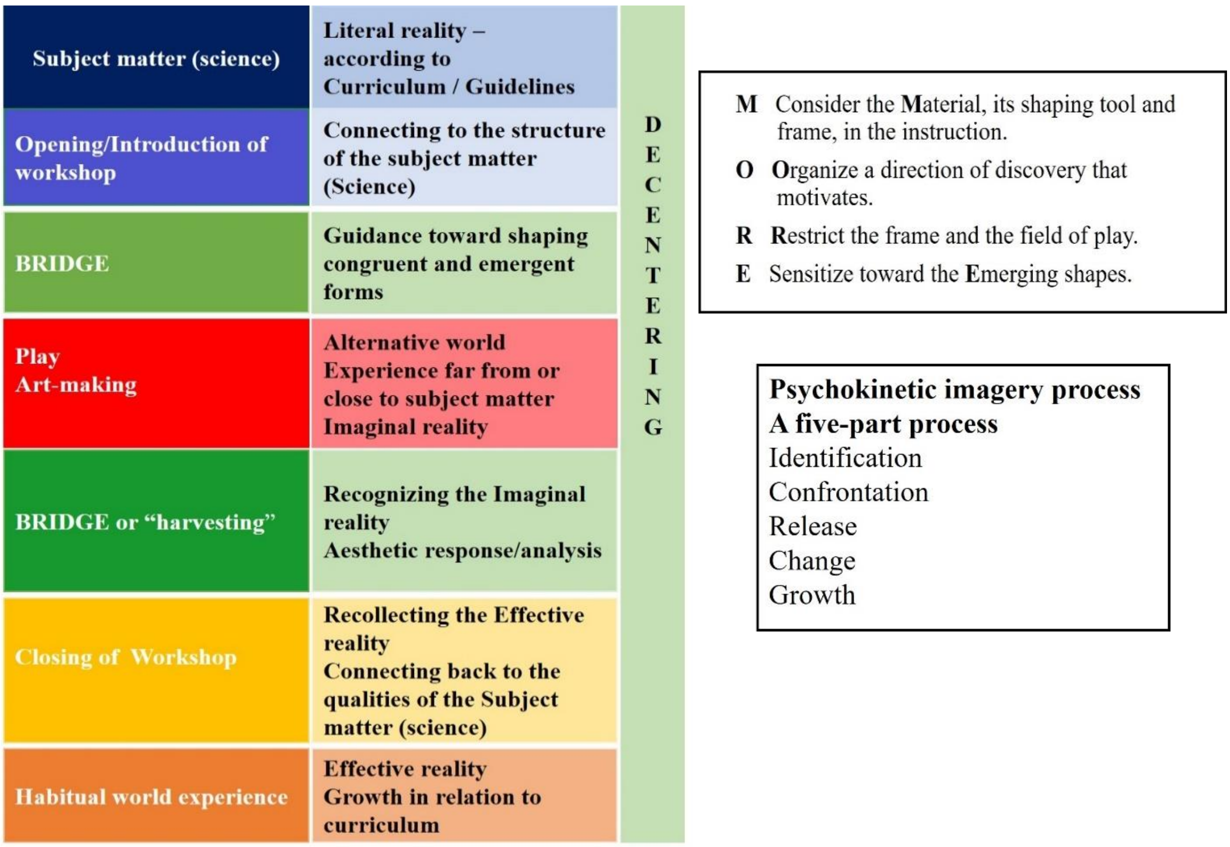

Figure 2. A structural didactic map of Aesthetic Learning Process (ELP) to the left, MORE – guidelines of intermodal work process (Knill, et al., 2005) **upper right and Intermodal arts model** (Halprin, 2003) **lower right.**

We sometimes have a preconceived notion that very well may situate us in the narrow manner of thinking and acting that marks the helplessness around a ‘dead-end’ situation. This position may originate from both imaginary and/or actual external factors such as the number of students, the timetables, the surroundings, social- and economic conditions, various disciplines and subject matter and the ability to reach the goals and quality of the curriculum. Focusing on the problematic situation has a tendency to produce more of the same and tends to worsen the situation. On the other hand, a *Decentering* induced attitude (Figure 2 left) and approach moves away from the fixed position offering a variety of possible and unexpected solutions. *Decentering* is used in order to slow down, find balance, stability and flow. In order to leave the time-sequence of literal reality controlled by a linear game-structure to a circularity movement of improvisation and play full of coincidences and synchronicity. The phenomenon of play is experienced in the ‘doing as if’ and in the here- and-now connected to all *Alternative world experience* (Figure 2 left). This phase is always framed by an entrance and an exit. The characteristics of all the ‘in and outs’ of the *Alternative world experience* are at the same time aspects of *Decentering* and contributes to the *Range of play*, the area of unconstructed movement of body, feelings and thoughts. Whereas creativity is often explained as an ability that allows people to discover a new solution to an old problem, *Art-making* is a multitude of perspectives, which alters into new knowledge. When provided with *Range of play* (Figure 2 left) the situational restrictions experienced by preconceived, stereotyped and normative thinking are contrasted.

However, restriction in the field of play is essential and may lead to further discovery and depth of subject matter. Restriction in for example constriction of material or time together with distinct and direct guidance providing directions of exploration in order to sensitise towards what is being experienced makes for a deeper understanding (Knill, et al., 2005).

Various theories of *Imagination* explain that imagination is not totally controllable; it is predictable only in its unpredictability. We can distinguish three realms of imagination: the dream space – (phantasy), the daydream and the artistic activity/play. The artistic activity combines the dream space and the daydream as the force of longing, which belongs to imagination as it yearns for the moment to manifest itself in the real world. The difference between imagination and phantasy is the embodiment of materiality with the former and the immaterial quality of the later (Levine, 1992).

The artistic activity is always a shared experience, in between group members, within a community and/ or individual, the tools and the materiality of the *Emerging shape*. The sharing happens not only through verbal description and communication but also through multiple sensory modalities (Knill, 2003).

Any art discipline, because of its connection with imagination, can evoke and find further expression in any other modality of imagination. Among all art disciplines we find a variety of sensory channels and imagination modalities. For example, within the visual arts the sensorimotor and tactile senses are engaged when we paint and a painting communicates not only through the visual image, but also through other imagination modalities. A painting may evoke a rhythm and a sound from which a story appears that depicts an act and a dance unfolds. In a similar way a poem can evoke sounds and movement (Knill, et al., 2005).

To educate in an integrated way one therefore must allow a synthesis that sharpens the sensory modalities seeing that the human instinct is multisensory.

Aesthetic Learning Process

An Aesthetic Learning Process based on *Intermodal Theory* (Figure 2) always consists of a five-part process. At the ESREA- conference 2017 our workshop was designed with the conference in mind and therefore with a focus on the middle parts of an intermodal Arts model process. The framework was the setting of the conference itself using the pre-understanding and predisposition of the participants as an agreement of shared literal reality (Knill, 2003; Halprin, 2003). This was the ethical starting point for the workshop at ESERA.

An Intermodal Expressive Arts five-parts process

The first part (identification) begins with an opening of the workshop by introducing the theme or subject matter, connecting these to the framework, in which the distribution of time is included and *Literal reality* (Figure 2 left*),* which can be described as a static and limited yet a familiar situation and cognizance (Knill, et al., 2005).

The second part (confrontation) is the BRIDGE. This phase is where the guiding and sensitising toward the qualities and characteristics to the theme and/ or subject matter happens. This approximation is done in an organized, clear and distinct direction of discovery using corporeal expression as a medium on the path to a broader and deeper awareness and adding layer on layer. The responsiveness and perception is thoroughly investigated both individually and together with others. It is equal important for the participants to start to discover one another as well as the subject matter or /and theme. It is also during this part where the *Rang of play* must establish a good enough spatial room for movement of body, feelings and thoughts (Figure 2).

The third part (release) consists of the *Alternative world experience.* This phase cannot start until the *Range of play* is sufficient in scope, depth and balance. The phase of *Art making* and *Play* is ready to begin provided that an agreement has been reached in regard to the materials, tools, oneself and the other participants. Then the Art making takes place - shaping the emerging forms. When the shaping act is followed by a shift in awareness often experienced and described as a sharpened understanding and change in the notion of time and conception of the learning process. The *Imaginal reality* (Figure 2 left) is an active part of the driving force in both receiving and welcoming of the emergent form.

The fourth part (change) is the BRIDGE again, but in this phase the crossing is from the *Alternative world experience* and *Art making.* In this step it is crucial to recognize and create awareness of the *Imaginal reality* and its motivation to co-exist. A good way of reaching a level of understanding is the *Aesthetic response* and *analysis*, which are both significant parts of *Harvesting* (Figure 2 left).

The fifth part (growth) is recollecting the *Effective reality*, connecting back to the beginning evaluating and reflecting over the process from the first step to the last. (Knill, et al., 2005).

An intermodal arts model is used during and within every sequential step as the *Aesthetic learning process* moves through the five part-work processes, looping, descending and ascending in-between and between the three levels of awareness and response, *the Mental level, the Physical level and the Emotional level* (Halprin, 2003). The three levels are equivalent significant components in the driving force behind this sometimes astute and exhaustive faculty that grasps, perceives, differentiates, distinguishes, integrates and conceptualizes the complexity of forms and patterns throughout and within the entire work process of *Aesthetic Learning* (Halprin, 2003) (Figure 3).

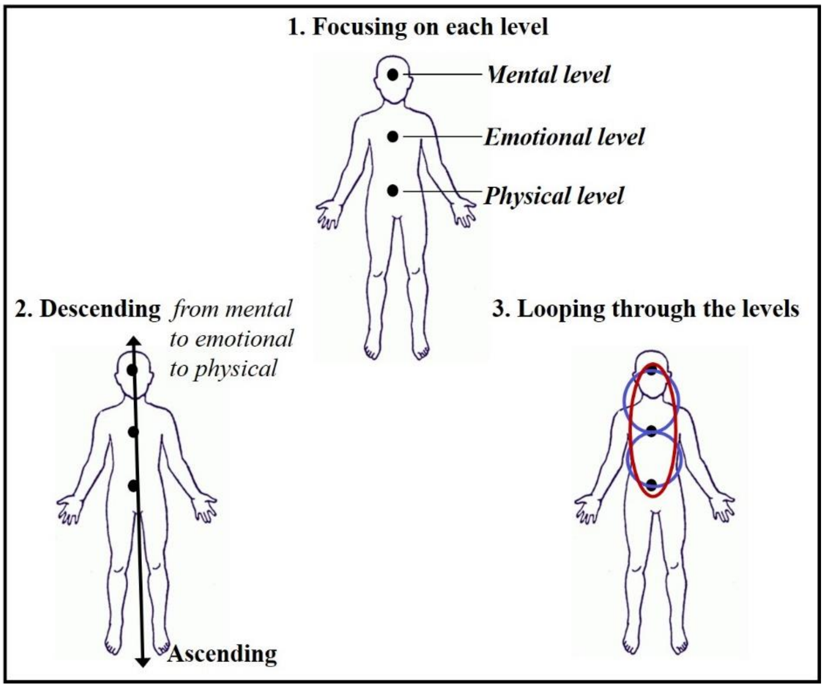

Figure 3. Three levels of awareness and response (Halprin, 2003)**.**

WORKSHOP

The workshop at ESERA -17 was directed by an art- and a science teacher and included examples of phenomena in science integrated with art performances in order to create deeper understanding through the construction of artefacts.

We constructed the workshop based on the setting of the conference as being a context of shared participation. We therefore incorporated the topic from one of the Conference Keynote speakers; the pivotal moment and we focused our work as a sort of play in three acts; the opening, the middle and the closing act. The mental image being a stroke out of a poem Lifting Belly by Getrude Stein; "..a rose is a rose is a rose.." as a form of direction of discovery (Figure 2 upper right and Figure 3). The work was carried out in three main parts:

Part 1. Opening and introduction to the workshop followed by Bridging.

In the first part the participants were doing different exercises embodying concepts in physics and creating relations with each other. Exploring the *Range of play* – organically forming groups of four quartets.

Part 2. Art-making

In the second part the participants constructed a kinetic mobile in groups of four.

Part 3. Bridging and *Harvesting.*

In the third part, the participants reflected, discussed and analysed their experience and understanding of different phenomenon, which had been addressed during the work process.

Altogether, 16 persons from different countries participated in the workshop.

First part

In order to achieve experience of concepts in physics such as gravity, friction, density, equilibrium and forces by aesthetic expressions, the workshop started with the participants standing in a circle in the centre of the aula. The following steps were improvisational work on the floor. Movements were done to feel gravity and to find the equilibrium in their own bodies (Figure 4 left). The instruction was to focus their own awareness as they moved and felt the space and the concept of "sliding" and then imagine and ask themselves if "sliding" has the colour of white, black or more a greyish nuance in between the white and the black. The next step was to find the spot where they sensed and felt the colour of "sliding". After finding the spot, the next step was to turn to the person, whom at the moment was physically closest to them and share what they had become aware of during the exercise. We then went on to explore other concept such as "heavy" and "light" in the similar manner. The participants told their impression of the concepts to the person next to them and finally to all members of the group. Examples of descriptions were: "black, it is fast in the dark when driving", "white - all colours together when it spins quickly".

The next instruction was to collect a piece of large white cotton sheet, a black crayon, a white crayon and a white panel with canvas structure. They were told to find and prepare a drawing area in somewhere in the aula - a place that made them comfortable enough. The following step was sensitizing towards the materials as well as to the surroundings by taken the white crayon in one hand and the black crayon in the opposite hand. Letting the crayons transform into dancers and themselves into world-renowned choreographers famous for creating choreographies representing different pivotal-moments. (This connects the work in progress to the outer framework of the conference and particularly to the topic raised by one of the Keynote speaker). They were then told to breathe and let the body, arms and torso get heavy as they opened their listening (ears) while they were instructed to close their eyes and let the dancers start dancing using the white square panel with structured canvas surface. The group members were instructed to share with another member of the group and then come together in the respective quartets observing and comparing their dance drawings within finding connections and similarities between their respective "blueprints" of the various choreographies (Figure 4 right). The blueprints of the dance were then used in opening up the second part of the workshop, the *Art-making* and construction of the quartet´s kinetic mobile.

Figure 4. Participants expressing different concepts in physics using their body (left) and crayons and panel.

Second part

The participants in groups of four used their blueprints to build a kinetic mobile. The instructions were to construct the mobile in at least two levels with two wooden sticks using the material presented on a table (Figure 5). All material was carefully planned to have different physical properties for example material with different elasticity such as rubber bands and to awake imagination. The mobile should also contain hanging things. The instruction was also that each person should think what the mobile tells them and the group was supposed to give it a name (Figure 6). This phase of *Alternative world experience* often draws group members closer to one another creating and bonding with a closeness in the relationships emerging during this phase. The relationships emerging are several, in between group members, in between the subject matter and the physical artefact leaving preconceived notions aside. The last step of in the *Art-making* and an *Alternative world experience* is *Aesthetic response*, the reflections were first done individually and then in small groups.

Figure 5. Material presented on a table.

Third part

We reconnected and reflected upon to the second and first part through *Aesthetic analysis* over the shared and achieved experience, recollecting the *Effective reality*, the learning and the altering of perspective and new insights that has taken place during the one-and-a-half-hour Workshop.

Figure 6. Example of kinetic mobiles constructed in the workshop.

Comments from participants:

Amazing that we created something from our mind.

Art is linked in the same way as curiosity in science.

Warming up is good to let go of the conference.

Needed several steps – not until we drew the dance – and I let go of the idea of doing right and wrong.

It takes a while before the thought comes.

I have never thought that I could create something like this along with people I do not know.

With such activities you can distinguish patterns.

It was an important and informative piece of the instructions about the hardness of the pen, 6B - I realized then that different hardness on pens can be investigated in chemistry and that the different grind of the canvas panel structure gives different results.

For the final evaluation of the exercises two questions were presented:

-What moment during the workshop awoke your curiosity or surprised /amazed you?

What new knowledge or experience will you bring with you?

"A surprise that came from the meanings that emerged."

"The black and white sequence. Then my mind opened for your instructions. I think I needed some time to disconnect from the reality of the conference."

"Bringing me an unexpected context. Not understanding the purpose, I opened up, it wakened my inspiration – with reduced experience like that can wake up hidden ideas."

"White movement above is invisible."

"I started to be very curious when we had to find the good place on the line between the grey and the white colour. My body decided for me what was the best place for me"

"The necessity to find a dialogue between the authenticity (defined by our own body) and the truth (defined by the science)."

PERFORMANCE ASSESSMENT OF PRACTICAL EXERCISES

The Swedish curriculum in the subjects of science have changed from being centred on reproducing facts to performance of skills when students should show their ability to use their knowledge in a context. One example is from the curriculum knowledge requirement in physics for grade E (passable) year 9 (Skolverket b, 2011, p. 127):

- Pupils can compare results with their questions and draw simple conclusions with some connection to the models and theories of physics. Pupils apply simple reasoning about the plausibility of their results and contribute to making proposals on how the studies can be improved.
- Pupils have basic knowledge of energy, matter, the structure and development of the universe and other physics contexts and show this by giving examples and describing these with some use of the concepts, models and theories of physics. Pupils can apply simple and to some extent informed reasoning where phenomena in daily life and society are linked together with forces, movement, leverage, light, sound and electricity, and show easily identifiable relationships in physics.

The teachers must create different learning situation to train these skills and to make it possible to assess performances. One possibility to assess practical exercises is to use an assessment rubric, here created from the knowledge requirements in physics in the Swedish curriculum for compulsory school and student's examples (Skolverket b, 2011) (Table 1). Such rubric is also useful during exercises integrating science subject matter with aesthetic expression where knowledge can be visualised (Mutvei & Mattsson, 2013).

By formation of a rubric for performance assessment with possible student answers provide opportunities for the teacher to participate in practical exercises in physics integrated with aesthetic expression. The teacher can investigate the knowledge of the students by listening to their discussions and how they solve problems while creating artefacts. The assessment rubric is a valuable tool for the teacher to evaluate their teaching and to give students more precise feedback (Mutvei & Mattsson, 2013).

Table 1. Assessment Rubric

	Sufficient	Good	Better
Use of theory	The student draws simple conclusions partly related to models and theories in physics. (*Gravity is the force that pull the weights down*)	The student draws conclusions based on models and eories in physics. (*Moving the string along the stick will move the equilibrium.)*	The student draws well founded conclusions out of models and theories in physics. *(The heavy weight on the short arm will balance the longer stick with the light weight like a lever.)*
Improvement of the experiment	The student discusses the observations and contributes with suggestions of improvements. (*If one put a heavier weight on one side it will compensate for the short arm.)*	The student discusses different interpretations of the observations and suggests improvements. *(The mobile is not hanging straight. It might be due to that one should take away the weight or move the string to get balance.)*	The student discusses well founded interpretations of the observations, if they are reasonable, and suggests based on these improvements which allow inquiries of new questions. (*The string stick due to friction and it is difficult to let it slide. We should look for other material that has lower friction)*
Explanations	The student gives simple and relatively well founded explanations. *(You need less force when you use a screwdriver if you hold it in the handle furthest away.)*	The student gives developed and well founded explanations. *(You will not need so much force when you cut the hedge if you use the hedge cutter with the longest handles.)*	The student presents theoretically developed and well founded explanations. *(You can move a heavy stone if you use a skewer with a long handle. The pivot point will be close to the stone having a short distance.)*
Relate	The student gives examples of similar processes as in the exercise related to questions about physical phenomena *(When I walk with my shoes on ice I have low friction. This is like when we measured how much force we needed to pull a box on different surfaces.)*	The student generalizes and describes the occurrence of similar phenomena in everyday life as in the exercise *(Design of mobile cases and shoe soles has to do with the need to create materials that have low or high friction.)*	The student discusses the occurrence of the phenomena observed in everyday life and the use of it and its impact on environment, health and society. *(It is important to use tires with structure on your car in winter to get higher friction otherwise you might have an accident.)*

SUMMARY

The participants of the workshop performed designed practical aesthetic activities as examples on how to reach a deeper, wider level of scientific understanding with several perspectives and layers of experience and knowledge. The workshop also gave examples of how to plan, implement and assess outcome of aesthetic learning activities in order to promote the development of the students' science knowledge content.

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