Part 1
Strand 1
Learning science:
Conceptual understanding

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INTRODUCTION TO STRAND 1

LEARNING SCIENCE: CONCEPTUAL UNDERSTANDING

Strand 1 focussed on Learning Science: conceptual understanding; within this strand, the research studies essentially address the process of learning science to develop understanding.

A central focus by all the researchers grouped under this strand is that learning science necessitates understanding science and this requires the comprehension of many ideas. As Bransford, Brown and Cocking (2000) point out: Learning with understanding suppose not to emphasize memory as often have been the case but to be able to use knowledge in different contexts and relate them. We have to take into account that a usable knowledge is not a mere list of disconnected facts. It needs connected and organized ideas around important nuclear concepts or models.

Therefore, researchers that have submitted their work on Strand 1 are aware that not only the facts are important in order to think and solve problems, but that students also (a) need to grasp how science has interpreted such facts and has built coherent models, and (b) have to insert the new knowledge into their pre-existing system of ideas and concepts.

So, as learning scientific concepts is not an easy process and as many teachers have experienced difficulties in this area, there has been much research devoted to addressing this problem, as shown by the large number of papers submitted to Strand 1. Also, the research shows different approaches to addressing this problem of learning with/for understanding.

Previous research in the 1980s and 1990s showed how students' conceptual difficulties were built on previous conceptions, e.g. compiled in the ICPE book*: Connecting Research in Physics Education with Teacher Education (1997).* This research was useful to identify the obstacles that must be overcome in student learning of the main topics in school curricula. Currently, however, the analysis of student's difficulties for conceptual understanding takes on new perspectives. Now, we find research studies to determine student difficulties in topics addressed at higher educational levels such as: Quantum, Relativity, Astronomy, Mechanistic-chemistry, etc. Genetics and Theory of Evolution are also recurring subjects of attention, often related with personal beliefs.

Building on previous research, the current research reported goes beyond identifying gaps in students' conceptual knowledge and conceptual errors, but aims to propose and evaluate teaching strategies that should enable teaching towards conceptual understanding. To this end, different "Learning progressions" have been presented in this Strand 1 to trace students' ideas (for example: E. Osman, L. Wang, H. Hamdan, G. Ampatzidis, etc). Other studies in this Strand suggest that an understanding of the microscopic view of structure of matter can be a good teaching strategy (J.P. Burde, W. Wu, etc.) or that student use of modelling to connect ideas and learn (e.g. C. Fazio, A. C. Dindar,) give rise to in-depth learning.

We also highlight the research evaluating various strategies and resources that have been studied to help the process of modelling, such as:

(a) Use of conceptual maps as a teaching-learning strategy (for example, R. Grobler, F. Lombard)
(b) Solve problems in different contexts (A. Ferreira)
(c) Propose Peer discussions (C. Wagner)
(d) Use of educational games, ICTs, etc. (A. Guerra, A. Almeida)

It is also noted that there are a number of research papers dealing with the process of learning as influenced by the social and cultural conditions of students and their beliefs about their environment (for example, J. Weber, V. Vieira).

Finally, we should remark that the research papers under Strand 1 have two characteristics:

(a) The specific concepts to be learnt or the models to be built are clearly defined in all the studies. That is, there are no pedagogical or general reflections applicable in all. They are focused on particular specific scientific topics.

(b) A qualitative methodology is most frequently used in order to collect and analyse the data. This provides a rich data set that helps researchers to understand in depth what happens along the process of building conceptual models, rather than merely counting the frequency of some particular conceptual construction.

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LEARNING PROGRESSIONS TO ENHANCE STUDENTS' UNDERSTANDING OF GENETICS

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Abstract: The purpose of this study was to develop a valid, coherent, and reliable learning progression-driven genetics unit based on students' misconceptions and difficulties and students' and teachers' recommendations for improving the curriculum and to investigate its impact on students' understanding of genetics. The study consisted of a descriptive phase followed by an intervention that used a quasi-experimental design with a design-based research approach. The descriptive phase investigated students' level of genetics understanding and evaluated the existing genetics curriculum. Questionnaires were administered to 729 students (Grades 7-12) and 20 biology teachers followed by semi-structured interviews with a representative sample of students and teachers. Data analysis revealed misconceptions in basic genetics concepts possibly caused by the incoherent genetics curriculum and the traditional teaching methods. Data from the first phase were used to develop, implement, and evaluate a learning progression and a learning progression-driven genetics unit which was validated by four biology teachers and implemented in one section of a Grade 9 class, while another section used the official textbook. Data came from pretests and posttests, classroom observations, student focus groups, and teacher questionnaires and interviews. Findings revealed that the genetics unit was coherent and logically sequenced but did not improve student understanding of genetics. Causes for the results and implications for practice are discussed.

Keywords: conceptual understanding, learning progressions, misconceptions

INTRODUCTION

Research-based reforms in science education have emphasized the importance of learning progressions (LPs) in promoting the understanding and retention of scientific concepts. LPs are "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time" (National Research Council (NRC), 2007). LPs are developmental and guided by theory and research on how students learn and on misconceptions associated with concepts (Duncan & Hmelo-silver, 2009). Accordingly, LPs provide a means for mapping and designing curricula, assessment tasks, and instructional materials that are coherent and logically-sequenced (Furtak, Roberts, Morrison, Henson, & Malone, 2010; Johnson & Tymms, 2011).

Research has shown that students encounter difficulties and develop misconceptions in many areas of modern genetics (e.g. Duncan & Reiser, 2007; Kurth & Roseman, 2001; Lewis & Kattmann, 2004; Tsui & Treagust, 2003) due to its interdisciplinary nature, high level of reasoning needed to interpret genetics information, difficulty to demonstrate genetics concepts in labs, outdated methods of teaching, and the low quality of science textbooks. Similarly, Lebanese educators claim that understanding genetics is impaired by the poorly sequenced, incoherent, and developmentally inappropriate genetics curriculum which needs to be revised in order to meet the needs of students. Although the review of literature reveals the existence of a LP in genetics (e.g., LP by Duncan, Rogat & Yarden, 2009), their LP has been described as conjectural and needs validation in classrooms (NRC, 2007), and there has not been any research on the topic in Lebanon.

Consequently, the main objectives of this study were to (1) develop a valid, coherent, and reliable LP-driven genetics unit based on students' misconceptions and difficulties and students' and teachers' recommendations for improving the curriculum and (2) investigate its impact on students' understanding of genetics.

Specifically, this study aimed to:

1. Determine teachers' perception of the coherence and organization of the Lebanese genetics curriculum across grade levels.
2. Determine teachers' perception of the effect of the Lebanese genetics curriculum on students' understanding of genetics concepts.
3. Identify the misconceptions and difficulties encountered by students during genetics instruction.
4. Examine ways of improving the genetics curriculum, from teachers' and students' perspectives, to achieve improved student understanding in genetics.
5. Develop a valid and reliable learning progression based on data collected from objectives 1-4, and previous research.
6. Investigate the level of the content coherence of the existing Lebanese national genetics curriculum and the learning progression-driven genetics unit.

In order to determine the effectiveness of the proposed learning progression, the newly developed genetics unit for Grade 9 was implemented and evaluated. This part of the study aimed to answer the following two questions:

1. Does instruction based on the learning progression produce better results for most students?
2. What are the major educative practices that might support the proper design and implementation of an LP-driven curricular unit?

METHODOLOGY

This study employed a mixed-methods approach in two main phases, a descriptive phase and a quasi-experimental design-based learning phase. During the first phase, participants consisted of 729 Grade 7-12 students and 20 biology teachers from three private and three public schools that used the same national biology textbook. This phase aimed to describe students' level of understanding of core genetics concepts, identify students' misconceptions and difficulties, and evaluate the scope and sequence of the existing genetics curriculum. For this purpose, teacher and student questionnaires were distributed and semi-structured interviews were conducted with a randomly selected representative sample of students and teachers. In addition, a systematic analysis of the genetics curriculum was done to evaluate its content in terms of possible conceptual gaps, organization, and coherence of core concepts. Data from student and teacher questionnaires was analyzed; means, standard deviations, frequencies, and percentages of responses on individual items were calculated and compared across grade levels. Student and teacher interview responses were transcribed and categorized by two researchers to insure validity of results. Then, a hypothetical LP was developed for Grades KG-12 and is centered, similar to that by Duncan, Rogat, & Yarden (2009), on two major constructs or big ideas: (1) The nature of genetic information and (2) the inheritance of genetic variation. One more sub-idea was added under the construct "Inheritance and Variation of traits" which addresses the mechanisms by which humans can control and manipulate genetic information through genetic technologies in order to improve different aspects of people's lives (e.g. Tables 1 & 2). This designed LP was used to write a genetics unit for Grade 9.

The second phase of the study used a quasi-experimental design-based research approach to investigate the effectiveness of the LP and the LP genetics unit in enhancing Grade 9 students' understanding of genetics concepts. This phase was implemented in two grade 9 sections (experimental and control) in a private school in Southern Lebanon. To assess the quality, feasibility, and reliability of the LP and LP-driven unit, a questionnaire was distributed to four experienced biology teachers who provided suggestions for improvement. Necessary modification where made, then, the unit was implemented in the experimental section (19 students) while the control section (20 students) received instruction using the existing national biology textbook. The same experienced teacher taught both sections. Data included results from a pretest and posttest given to students before and after implementation of the LP unit respectively; results were analyzed to produce frequencies and percentages of correct responses on each test item. To determine if the genetics unit enhanced student learning, gain scores were compared. In addition, classroom observations were conducted to evaluate the quality of teaching and identify the difficulties encountered by both teacher and students. After implementation, focus groups were conducted with a sample of students from the experimental and control groups to explore their positions regarding the existing and LP-driven genetics units. The teacher was also interviewed and a questionnaire was given to four biology teachers to explore their opinions regarding the LP-unit as it compares to the existing one. Data were transcribed and independently analyzed by two researchers to produce categories of students' views about the unit and insure validity of results.

RESULTS

Results of the study are summarized below:

Phase 1

1. Students of all grade levels showed inadequate conceptual understanding and misconceptions in basic genetics concepts such the role of DNA, difference between gene and allele, the relationship among DNA, genes and proteins, meiosis, mitosis, pedigree analysis, cloning, schematizing gametes, protein synthesis and DNA detecting techniques.

2. Students' level of conceptual understanding tended to increase with advancing grade levels.

Table 1.

Designed Learning Progression in Modern Genetics across Grade Levels on the Big Idea of "The nature of genetic information"

Learning Progression in Modern Genetics

Question*: How do genes influence how we, and other organisms, look and function?*

Big idea: *All organisms have genetic information that is universal and specifies the molecules that carry out the functions of life. While all cells have the same information, cells can regulate which information is used (expressed).*

Components of Big Idea	Level 1: KG-3	Level 2: 4-6	Level 3: 7-8	Level 4: 9-10	Level 5: 11-12
(A) All organisms have genetic information that is hierarchically organized	Living organisms possess characteristics that can be recognized and described as either similar or different	The nucleus of the cell controls how organisms grow, develop, and function	Humans, animals, plants, fungi, and bacteria have genetic information stored in chromosomes inside the nucleus of their cells.	The genetic information is found in the chromosomes which are made up of DNA that consists of 4 units: A, T, C, and G. DNA molecules make up chromosomes that make up our genome. Most sexually reproducing organisms have the same sets of chromosomes. All cells of an organism have the same two chromosomal sets (except sex cells). Several genes interact to produce the same trait	Genes are nucleotide sequences within the DNA molecule. Genes are of two kinds: functional genes which determine traits and homeotic genes which regulate the action of functional genes and control the macro-organizations of body parts
(B) The genetic information contains universal instructions that specify protein structure			Genes are instructions for how organisms grow, develop, and function	Genes are instructions for molecules (many of which are proteins) that carry out functions within the organism. All organisms use the same genetic language for their instructions	The genetic code is translated into a sequence of amino acids that makes up the protein. Almost all organisms use the same genetic code

Table 2.

Designed Learning Progression in Modern Genetics across Grade Levels on the Big Idea of "The inheritance of genetic variation"

Learning Progression in Modern Genetics

Question*: Why do we, and other organisms, vary in how we look and function?*

Big ideas: ***There are patterns of gene transfer across generations. Cellular and molecular mechanisms drive these patterns and results in genetic variation. The environment interacts with our genetic make-up leading to genetic variation. Man can alter and manipulate the genetic make-up of organisms for the benefit of human life.***

Components of Big Idea	Level 1: KG-3	Level 2: 4-6	Level 3: 7-8	Level 4: 9-10	Level 5: 11-12
(H) Environmental factors can interact with our genetic information			The environment can affect our traits. Even organisms that are related may end up looking or behaving differently	The environment can influence cell function throughout changes at the protein level (type and amount)	Environmental factors can cause mutations in genes, or alter gene expression
(I) Man can alter and modify the genetic information. Advanced technology has enhanced this action.		Man uses several techniques to improve the quality of animals and plants	Man can manipulate the genetic information and cause change in traits	New varieties of farm animals and plants arise by transgenesis and other gene transfer techniques used by man. Genetic engineering is used to provide therapy for certain genetic diseases	Bizarre and new creatures occur as a result of gene manipulation by man. Advanced DNA technology helps improve the health quality of humans

3. Students across all grade levels had a low level of genetic literacy as they failed to answer questions on how genetics related to society, technology, and the environment.

4. Students and teachers attributed difficulty in understanding genetics concepts to the poor quality of the national biology textbook which lacks coherence and logical sequencing of concepts, is overloaded with material, does not encourage critical thinking, does not match students' cognitive level, and does not link genetics to everyday life. Students also underlined the use of traditional teaching methods as another major reason for the difficulty they face in understanding core ideas in genetics.

5. Content analysis of the genetics curriculum showed lack of developmental progression across the grade levels, misalignment between content and objectives, absence of ethical and moral life-related issues, and shallow coverage of STS genetics issues.

Phase 2

1. Teachers' and students' evaluation of the LP-driven genetics unit revealed that the objectives and content were aligned, the concepts were coherent and logically sequenced, the content promoted genetic literacy, and the activities and assessment items encouraged critical thinking. This was consistent with the students' opinions in the focus groups in which they indicated that the newly designed genetics unit had a clear and logically organized content which is enriched with quality illustrations, figures, questions and real-life examples that enhanced their understanding of genetics.

2. Despite the improvement of the genetics curricular unit, a comparison between the gain scores of the experimental and the control groups showed an almost equal performance on most of the pretest/posttest items (Table 3). Also, students still found the concepts of mitosis and meiosis very difficult and confusing.

Table 3

Distribution of Final Averages of Experimental Group (N=19) and Control Group (N=20)

Exam	**Experimental**			**Control**		
	M	SD	Range	M	SD	Range
Monthly 1	11.3	4.3	5.0-19.0	10.5	4.4	5.0-19.0
Monthly 2	10.3	3.6	6.0-18.0	11.7	3.6	6.0-17.0
Mid-year	11.8	4.7	4.0-19.0	12.1	4.4	5.0-19.0
Total Average	11.1*	0.6	5.0-18.3	11.4*	0.7	5.0-18.3

*No significant difference between the score of the different groups

DISCUSSION & CONCLUSIONS

Although there is a slight increase in the conceptual understanding of students across grade levels, a majority of the Lebanese students seem to have misconceptions and encounter difficulties in core genetics concepts similar to students in other developed countries. Results suggest two possible sources of these misconceptions and difficulties: the curriculum itself and traditional instruction. This might be due to lack of coherence and logical sequencing in the existing curriculum and the poor quality of content, activities, and illustrations, results that are consistent with previous research on other genetics curricula (Roseman, Caldwell, Gogos, & Kurth, 2006). Furthermore, when the content does not emphasize ethical and moral genetics-related issues and barely tackles science/technology/society issues, it is not surprising that existing genetics curricula do not promote the development of genetically literate citizens who can apply knowledge to their daily life (e.g., Lewis & Kattmann, 2004).

Moreover, although the LP-driven genetics unit favors group-discussion, use of inquiry, lab activities, and technology in instruction, classroom observations showed that teacher-centered methods dominate genetics instruction. This receptive type of instruction is characterized by a lack of accommodation of students' abilities and interests, and the lack of use of technology and/or a variety of scientific resources which are integral to the teaching of science. On the contrary, the student-centered approach illustrated in the designed unit is imperative, especially for deep understanding of the abstract concepts of genetics.

When asked to explain her approach, the biology teacher argued that time constraints, the overloaded curriculum, and student preparation for official exams resulted her traditional teaching methods. Such impediments may lower students' motivation to learn genetics.

Moreover, classroom observations provided evidence that the language of instruction (English) is another major factor which might hinder students' learning, since it is different from their native tongue (Arabic).

Jointly, all the factors mentioned above are possible explanations for Lebanese students' persistent difficulties in understanding genetics concepts. When students do not have a firm grasp of basic genetics concepts in earlier grade levels, they carry their misunderstandings and misconceptions with them as they progress to higher grade levels. As a result, students are reaching higher grade levels without an adequate knowledge base that is necessary for understanding more complex genetics concepts.

In terms of validating the effectiveness of the genetics unit that was based on the LP, teachers' and students' feedback provided evidence that the new unit addressed the major problems of the existing curriculum. Surprisingly, however, findings of this study showed that students from both experimental and control groups performed equally well on most of the post-test items. One possible reason may be the fact that the teacher used some activities included in the new genetics unit for both classes because of her perception that the unit was better adapted to students' needs. This could have happened when the researcher was not conducting classroom observations. Other reasons include the lack of proper implementation of the unit, the teacher's weak content knowledge, among other possible reason.

This study presents several implications for practice. First, there is a need for an extensive revision of the Lebanese genetics curriculum. Second, proper sequencing of core concepts and sub-concepts is necessary, using LP as a framework, to enhance students' understanding of genetics, but alone is not sufficient. The best curriculum would fail if teachers are not offered the opportunity to be trained in strategies for the proper implementation of the designed curriculum. In addition, student-related factors (e.g. prior knowledge and language proficiency) need to be taken into consideration. As a result, it is highly recommended that schools, curriculum designers, and universities establish partnerships with the government to refine scholastic programs based on research in an attempt to nurture students, the knowledgeable citizens.

REFERENCES

Duncan, R.G., Rogat, A., & Yarden, A. (2009). "A learning progression for deepening students' understandings of modern genetics across the 5th-10th grades". *Journal of Research in Science Teaching, 46*(6), 655-674.

Duncan, R.G., & Reiser, B. J. (2007). Reasoning across ontologically distinct levels: Students' understandings of molecular genetics. *Journal of Research in Science Teaching, 44*(7), 938-959.

Duncan, R., & Hmelo-silver, C. (2009). Editorial: Learning progressions: Aligning curriculum, instruction and assessment. *Journal of Research in Science Teaching,46* (6),606-609.

Johnson, P., & Tymms, P. (2011). The emergence of a learning progression in middle school chemistry. *Journal of Research in Science Teaching, 48*(8), 849-877.

Kurth, L.A., & Roseman, J. (2001). *Findings from the high school biology curriculum study: Molecular basis of heredity.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching. St. Louis, MO.

Lewis, J., & Kattmann, U. (2004). Traits, genes, particles and information: Re-visiting students' understandings of genetics. *International Journal of Science Education, 26*(2), 195-206.

Furtak, E. M., Roberts, S.A., Morrison, D.M, Henson, K., Malone, S. (2010). *Linking an educative learning progression to teacher practice: Results of an explanatory study.* Paper presented at the annual meeting of the American Education Research Association, Denver, CO.

National Research Council (2007). *Taking science to school: Learning and teaching science in grades K-8. Committee on Science Learning Kindergarten through Eighth Grade.* R.A. Duschl, H.A. Scweingruber, & A.W. Shouse, (Eds.). Washington, DC: The national Academic Press.

Roseman, J., Caldwell, A., Gogos, A., & Kurth, L. (2006). Mapping a coherent learning progression for the molecular basis of heredity". *Paper presented at the National Association for Research in Science Teaching Annual Meeting.* San Francisco, CA.

Tsui. C.Y., & Treagust, D. F.(2003). Genetic reasoning with multiple representations. *Journal of Research in Science Education, 33*, 111-135.

PHYSICS STUDENTS' UNDERSTANDING OF FUNDAMENTAL PRINCIPLES IN QUANTUM PHYSICS

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Abstract: Quantum physics is a fascinating but also challenging topic in physics at pre-university level. This study has investigated how 170 students in upper secondary schools in Norway understand the concept of quantization and the wave-particle duality for light while working with digital resources developed in the project ReleQuant, where qualitative understanding and use of language is emphasized. Data were collected by means of students' written responses to tasks on the digital platform, and by discussions between peers recorded on students' own cell phones. It was found that the concept of quantization was poorly understood and often mistaken as quantification. For the wave-particle duality it was found that many students refer to the dual nature of light without paying attention to the contradiction between the models. However, some good student responses also indicate that qualitative understanding of quantum physics is possible even on pre-university level. The results contribute to the relatively scarce research literature on student understanding of modern physics on pre-university level. In ReleQuant, results are also used for further development of teaching resources, in line with the Educational Design Research methodology. New versions of the resources pay attention to students' problems in understanding of the concept of quantization and emphasize the contradiction between a wave model and a particle model for light in a classical sense. Implications are discussed for design of teaching resources that support students in reflecting on how quantum physics breaks with classical physics and on its epistemological implications.

Keywords: Quantum physics, student conceptions, Educational Design Research.

INTRODUCTION

Quantum physics has wide-ranging consequences for our worldview as well as for modern technology development. Theories in quantum physics break with our everyday experience of natural phenomena and with classical physics in fundamental ways that often fascinate young people. However, relatively little research has been undertaken to investigate students' conceptions and learning processes in quantum physics on pre-university level.

In contrast to the situation in most other countries, the Norwegian curriculum for physics in upper secondary school gives opportunities to explore interpretations of quantum physics and relativity and discuss the philosophical and epistemological consequences of theories in modern physics (Henriksen et al., 2014). The curriculum provides opportunities for students to explore the philosophical foundation for quantum physics, how it breaks with classical physics and its epistemological consequences. However, research also indicates that many physics teachers find it challenging to teach this part of the curriculum (Bungum, Henriksen, Angell, Tellefsen & Bøe, 2015).

This paper reports results from the project ReleQuant, which combines research and development in developing digital teaching resources in quantum physics and theory of relativity by means of methodology from Educational Design Research (see Bungum et al., 2015). In the development of resources we emphasise qualitative understanding in line with the curriculum requirement, students' reflection and their use of written and oral language in the learning process. The teaching material also exposes students to the nature of science in terms of how quantum physics developed historically, that physicists still disagree on interpretations, the implications of modern physics for our view of the world, and the use of quantum physics in modern technology.

The specific study presented here investigates how Norwegian upper secondary physics students interpret fundamental principles in quantum physics before and during work with the digital teaching resources developed in the project ReleQuant. We focus on two fundamental principles in quantum physics; the wave-particle duality for light and the concept of quantization.

Research questions for the study are:

1. *How do upper secondary physics students interpret the wave-particle duality for light?*
2. *How do upper secondary physics students interpret the concept of quantization?*

The results contribute to the further development of ReleQuant resources, and in the discussion in this paper we will point to specific changes made in the resources based on the results. The study also has a more general value by throwing light on how upper secondary school students may perceive fundamental principles in quantum physics, and the opportunities and challenges in teaching quantum physics in qualitative ways on pre-university level.

PREVIOUS RESEARCH ON STUDENTS' CONCEPTIONS IN QUANTUM PHYSICS

Whereas a large body of research has documented students' conceptions and learning within a range of topics in classical physics (see Duit, 2009), considerably less research has been undertaken to investigate students' understanding and learning in modern physics. In mechanics, for instance, research has focused on how the physical description of e.g. motion and forces appears counterintuitive compared with students' everyday experiences (Driver et al., 1994). In quantum physics and relativity, challenges are of a different nature, since these topics concern phenomena that cannot be visualized or experienced directly and where classroom experiments may be difficult or impossible to undertake.

Research on university students' conceptions of quantum physics indicates that their understanding is often fragmented and dominated by isolated facts not fitted into an internally consistent conceptual framework (Hadzidaki, 2008). This may be due to how quantum physics on university level is dominated by mathematics and abstract formalism. Pospiech (2000) pointed out that even if quantum physics cannot be fully understood without mathematics, the mathematical formalism often hides the philosophical issues important for understanding the full depth of modern physics. Based on a study of pre-university students' understanding of quantum physics, Ireson (2000) gave five recommendations for teaching the topic: 1. Avoiding reference to classical physics; 2. Teaching the photoelectric effect by beginning with electrons rather than photons; 3. Using statistical interpretations of observed phenomena and avoiding dualistic descriptions; 4. Introducing the Heisenberg uncertainty principle for ensembles of quantum objects at an early stage; and 5.Avoiding the Bohr model in the treatment of the hydrogen atom.

Ayene, Kriek and Damtie (2011) investigated university students' conceptions of the wave-particle duality, and found that most students described light in terms of classical models of waves and particles, or as mixed models with aspects of quantum physics combined with classical models. Olsen (2002) found that the wave-particle duality was poorly understood by senior high school students in Norway, and some students clearly demonstrated misconceptions rooted in a classical physics worldview. One misconception identified was the view of light as particles moving in a wave-shaped trajectory. Cheong and Song (2014), in their study of university student conceptions, identified three levels of meaning of duality. The first level entails that light has both particle and wave properties, without any reference to a wave function. On the second level, students' models include principles from quantum mechanics such as a wave function and Schrödinger's equation. The third level includes an understanding of different interpretations of quantum theory, linking the theory to experimental observations. The first level of meaning of duality is most relevant to the Norwegian senior high school physics curriculum, since it describes a qualitative approach to quantum physics. However, the curriculum states explicitly that students should reflect on philosophical aspects of quantum physics and how it breaks with classical physics. This requires that students' understanding of wave-particle duality moves beyond a statement that it is "both waves and particles".

Singh (2008) pointed to the importance of visualizations for students in order to build links between formal and conceptual aspects of quantum physics. Hadzidaki (2008), discussing teaching and learning in quantum physics, argued that students need to be made aware of the ways in which quantum physics represents a break with the principles of classical physics. This break and its epistemological consequences is an important objective in the Norwegian physics curriculum. Similarly, Renstrøm (2011) in her historically based teaching approach emphasized how quantum physics challenges basic assumptions in classical physics such as continuity, determinism and locality.

METHOD

Data for the study presented in this paper were gathered from students' work with the digital ReleQuant material in physics classes during three subsequent cycles of development over the period March 2014 - March 2015. Eight classes at five different upper secondary schools participated, involving around 170 students taught by their regular teacher.

Two kinds of data were collected for this study. Firstly, written student responses to questions in the ReleQuant teaching module were collected through the digital platform. For light, this firstly involved a question at the beginning of the teaching where students are invited to describe in writing what they think light is, based on their prior knowledge. Secondly, student discussions were recorded when students were asked to compare their written responses in pairs. For quantization, students were first challenged to suggest everyday entities that are quantized and respond in writing. Then they did audio recordings of peer discussions on these suggestions. Student discussions in pairs were recorded on the students' own cell phones and e-mailed by students to their teacher after the session.

Students' responses (written and oral) were analyzed qualitatively using a thematic approach (Braun & Clarke, 2006) to identify patterns and themes within student responses. To some extent we have counted responses and reported as percentages of responses within categories of responses. However, since students partly worked in pairs and student numbers were varying during the sessions, we present the results mainly qualitatively with semi-quantitative measures in order to indicate how prevalent various student conceptions appear to be.

RESULTS

Students' conceptions on the wave-particle duality

The most prevalent conception in students' responses was light as waves *and* particles. Some of these students described the experimental evidence supporting each view, in particular interference patterns as a sign of wave properties. However, many students dealt with the two models in combination without further elaboration. For example, one student wrote:

> *Light is energy in the form of small particles, photons. Light gets different colors depending on which wavelength it has.*

These responses indicate that students hold parallel conceptions of light as waves and particles, without considering the contradiction between these two models. Previous results from the project demonstrated that 40% of student responses reflect this kind of view classified as *uncritical duality* (Gjerland, 2015).

A handful of respondents expressed a misconception concerning the wave-particle duality, describing photons as performing a wave motion, for example

> *The particles move in «wave trajectories» through space*

A relatively small proportion of respondents expressed epistemological reflections on the fact that scientists still discuss the nature of light:

> *It is hard to determine what a photon is. Even researchers disagree, there are many explanations and definitions. They behave differently depending on the perspective you take*

Recorded oral discussions among students confirm the impression that students may think of light in different ways without recognizing any contradiction. For example, in the following dialogue student A speaks of light as electromagnetic waves, while student B explains it as a stream of photons and small particles:

> *A:* *What are photons and light, really?*
>
> *B:* *Well, light is...*
>
> *A:* *It's an electromagnetic wave, isn't it? …that is sent out from a glowing body.*
>
> *B:* *Yes.*
>
> *A:* *Yes?*
>
> *B:* *Light is simply a stream of photons, then.*
>
> *A:* *Yes, you could say that.*
>
> *B:* *Photons, then, are…*
>
> *A:* *And then we have -*
>
> *B:* *Photons are very small, indivisible particles.*

The students here seem to think they agree on a common understanding, yet they refer to very different models for light.

Students' conceptions of quantization

Concerning *quantization*, respondents were asked to think of everyday examples of quantized entities. Many came up with adequate examples such as the number of book pages in a library and the number of persons in a room.

However, the students' audio-recorded discussions reveal that the ideas underpinning their examples often entail a weak understanding of what quantization means. Their ideas range from quantization as any entity that is countable as integer numbers (in principle or in practice, e.g grains of sand in Sahara) or limited in number, to ideas of values as fixed (e.g.

the mass of an electron), conserved (e.g. the amount of water on earth) or predestined (e.g. the number of teeth a human gets). Many also mixed up the phrases (and in many cases the concepts) *quantizatio*n and *quantification*, as in this statement where the student perceives quantization as entities that can be counted as integer numbers:

> *Well.. Quantification is, well it is to divide into certain levels, like in everyday life you can say that you have a certain number of friends. You cannot have half a friend. You can have 1,2,3… You can have an integer number.*

Analysis undertaken by Myhrehagen (2015) indicates that about 80 % of students understand quantization as quantification, that is, something that can be assigned a number. Only 8 % of student utterances in writing or in discussions exposed an understanding of quantization as discontinuity. The following response, where the student uses a chain as an analogy, is a very good, but rare, example of how some students expose a good understanding of what quantization means:

> *Like a chain has a smallest value of length. Because the length must be divisible with the length of one chain ring, in contrast to a thread that you can cut in any length you want. So the thread will be an example of something continuous when you cut the length, while a chain sort of has to make steps in lengths, and is not continuous, because you must consider the chain rings. So the chain is quantized.*

For most students, however, it was challenging to find good everyday examples of quantized entities in the sense the concept is used in physics. The problem is reasonable, since quantization beyond the trivial integer number examples is not easy to find in everyday life.

DISCUSSION AND CONCLUSIONS

This paper has investigated pre-university physics students' conceptions of fundamental principles in quantum physics. Although our sample is not adequate for a statistical generalization, we anticipate that similar student conceptions also will be present in other classrooms. The results indicate that most students are well aware that light can be described as both waves and particles. Some refer to the experimental basis for the two descriptions, but only few respondents discuss the two models as complementary or (seemingly) contradictory.

It seems that students try to combine the wave and particle view of light in ways that avoid the contradiction between the two models. For some, this leads to the misconception described by Olsen (2002), that the wave-particle duality means that particles are moving in a wave-shaped trajectory. Others speak of 'energy packages' in ways that fit how photons often are drawn in textbooks as short pieces of a wave. This visualization of a photon helps students combine a wave and a particle in one single conception, but may mask the break between classical physics and quantum physics, and may not be constructive in developing a deeper understanding of quantum physics. The results as a whole confirm the results reported by Ayene, Kriek and Damtie (2011), where students stick to classical conceptions and images in interpreting quantum physics.

These results indicate that teaching of quantum physics should emphasize how quantum physics break with classical physics in fundamental ways. For the Wave-particle duality, this means that students should be made aware of the contradiction between a wave model and a particle model for light interpreted in a classical sense. This might help students avoid the typical misconceptions that are rooted in classical models. Exposing to students how different and conflicting interpretations exist among contemporary physicists may also stimulate their own epistemological reflections and illustrate how science is in continuous development, thus supporting a more nuanced view of the nature of science.

In line with Educational Design Research as a research methodology, the resources developed in the ReleQuant project are adjusted based on the research results. Figure 1 shows a screenshot from the next version of teaching resources, designed to make students more aware of how classical conceptions of a wave and a particle can not be combined in meaningful ways, since a wave is extended in space while a particle is a point (or a very small object). Students are here encouraged to discuss whether it is possible that light can be simultaneously a wave and particles, in order to make them aware of the shortcomings of classical models in quantum physics.

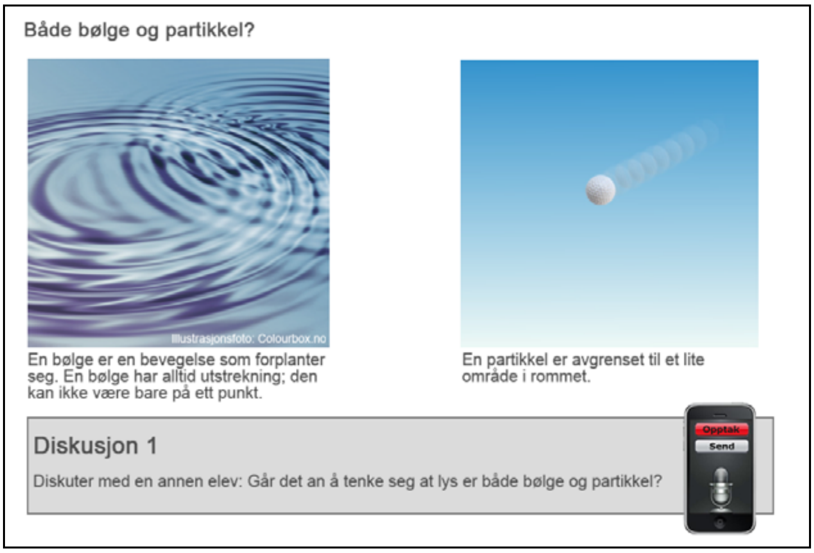

Figure 1. Screenshot of ReleQuant page emphasizing how a wave model and a particle model for light contradict each other in a classical sense.

For quantization, recorded student discussions indicate that a surprisingly large number of students hold insufficient understanding or mistaken ideas on what the concept ‘quantized’ means. Many respondents focused on how quantization concerns countable entities, whereas very few responses involved the idea of discrete levels or values. Some responses seem to be influenced by a confusion of the concept ‘quantized’ with ‘quantified’.

The first prototype of the ReleQuant resources encouraged students to use everyday examples in order to elaborate on the concept of quantization. However, as results from the trials in classrooms exposed that many students had weak conceptions of quantization and that some students acquired limited or mistaken understanding by means of everyday examples, the resources were changed in this regard. Rather than focusing on everyday examples, the next version of the resources invite students to go deeper into the physics and how the issue of quantization can be traced back to ancient philosophy of nature. Even if research in physics education has warned against the use of the Bohr model for the atom (e.g. Ireson, 2000) in teaching modern physics, we find it useful to build on students familiarity with this for illustrating quantization of energy. Figure 2 shows a screenshot of the resources where energy levels in the hydrogen atom are contrasted to the continuously changing kinetic energy of an oscillating spring in order to illustrate the difference between quantization and continuity in the case of energy. The presentation of quantization from a historical perspective is shown in Figure 3. This includes links to Einstein presentation of the photon in original and translated version.

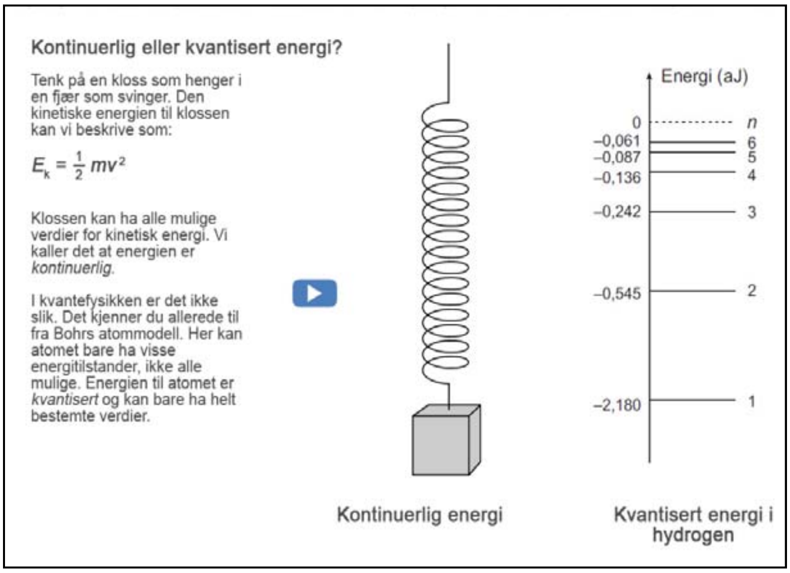

Figure 2. Screenshot from ReleQuant page comparing continuous energy in a spring and quantized energy in the Hydrogen atom.

Figure 3. Screenshot from ReleQuant page presenting the concept of quantization from a historical perspective.

The use of language and student discussions in ReleQuant has contributed to exposing student conceptions in quantum physics as multifaceted. Even if students are often able to give adequate examples and definitions such as those found in textbooks, their discussions reveal that fundamental concepts in quantum physics are poorly understood. However, some good responses from students indicate that a deeper qualitative understanding of quantum physics is possible even on pre-university level, in the case of wave-particle duality this means progressing through the second and third level of meaning of duality as described by Cheong and Song (2014).

As Pospiech (2000) has suggested, there is a clear need in teaching to go deeper into what fundamental concepts mean when teaching about quantum physics, and to express their significance for our understanding of the physical world. Moreover, more research is needed – and will be continued in repeated cycles of design and classroom trials in ReleQuant – to establish evidence-based knowledge on how teaching material can be designed to support students' qualitative understanding and epistemological reflections in physics.

Acknowledgement

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References

Ayene, M., Kriek, J., & Damtie, B. (2011). Wave-particle duality and uncertainty principle: Phenomenographic categories of description of tertiary physics students' depictions. *Physical Review Special Topics - Physics Education Research, 7*(2), 020113.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101.

Bungum, B., Henriksen, E. K., Angell, C., Tellefsen, C. W., & Bøe, M. V. (2015). ReleQuant - Improving teaching and learning in quantum physics through educational design research. *NorDiNa, 11*(2), 153-168.

Cheong, Y. W., & Song, J. (2014). Different Levels of the Meaning of Wave-Particle Duality and a Suspensive Perspective on the Interpretation of Quantum Theory. *Science & Education, 23*(5), 1011-1030. doi: 10.1007/s11191-013-9633-2

Driver, R, Asoko, H, Leach, J, Scott, P, & Mortimer, E. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher, 23*(7), 5-12. doi: 10.3102/0013189x023007005

Duit, R. (2009). Bibliography - STCSE. Students' and Teachers' Conceptions and Science Education Retrieved 01.12, 2015, from http://archiv.ipn.uni-kiel.de/stcse/

Gjerland, M. (2015). *Elevers oppfatning om lys og bølge/partikkel-dualismen [Students' conceptions of light and the wave-particle dualism].* Master thesis, The Norwegian University of Science and Technology, Trondheim, Norway.

Hadzidaki, P. (2008). 'Quantum Mechanics' and 'Scientific Explanation' An Explanatory Strategy Aiming at Providing 'Understanding'. *Science & Education, 17*(1), 49-73. doi: 10.1007/s11191-006-9052-8

Henriksen, E. K., B. Bungum, B., Angell, C., Tellefsen, C. W., Frågåt, T., & Bøe, M. V. (2014). Relativity, quantum physics and philosophy in the upper secondary curriculum: challenges, opportunities and proposed approaches. *Physics Education, 49*(6), 678.

Ireson, G. (2000). The quantum understanding of pre-university physics students. *Physics Education, 35*(1), 15-21.

Myhrehagen, H. V. (2015). *Fysikkelevers forståelse av kvantefysikkens erkjennelsesmessige sider og dens prinsippielle brudd med klassisk fysikk. Master thesis.*, The Norwegian University of Science and Technology, Trondheim.

Olsen, R. V. (2002). Introducing quantum mechanics in the upper secondary school: a study in Norway. *International Journal of Science Education, 24*(6), 565-574.

Pospiech, G. (2000). Uncertainty and complementarity: the heart of quantum physics. *Physics Education, 35*(6), 393.

Renstrøm, R. (2011). Kvantefysikkens utvikling i fysikklærebøker, vitenskapshistorien og undervisning. PhD thesis. University of Oslo, Oslo.

Singh, C. (2008). Interactive learning tutorials on quantum mechanics. *American Journal of Physics, 76*(4), 400-405.

CONCEPT MAPPING AS A TEACHING-LEARNING STRATEGY IN NATURAL SCIENCES CLASSROOMS

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Abstract: Learning is a life-long process and constructing a good learning framework for students is essential in order for them to be productive students throughout their lives. To construct and connect concepts to develop a framework which links content in a concept building process seems to be a better option than to merely flooding students with overwhelming terms and knowledge without making logical connections. According to Cheema and Mirza (2013), Buldu and Buldu (2010), Horton, McConney, Gall, Woods, Senn and Hamelin (1993) concept mapping is one strategy, which has shown promise in being a significant teaching-learning strategy. After various informal discussions with Natural Sciences teachers it became clear that only a few of them utilise concept maps as a teaching-learning strategy. This study investigated the role of concept mapping as a teaching-learning strategy in South African Natural Sciences classrooms. A quasi-experimental design was utilised for this study. Two Grade 8 Natural Sciences classes took part in this investigation, 48 students participated in the study, 24 within the control group and 24 within the experimental group. Both groups completed the pre-test questionnaire, both groups wrote the pre-test assessment on the topic 'scientific investigation', both groups wrote the post-test assessment on the learnt topic, and only the experimental group completed the post-test questionnaire. The results revealed that concept maps play an important role in Grade 8 Natural Sciences classrooms and although students prefer constructing maps in class, to constructing it on their own, they do use concept maps as a study strategy in preparing for the exams.

Keywords: concept mapping, science education, teacher training

BACKGROUND AND FRAMEWORK

Meaningful learning in the Natural Sciences classroom refers to implementing a way of learning, where the new knowledge to be acquired is related to existing ideas and knowledge (Ausubel, 1968). Concept mapping has been rising in stature as an essential teaching learning tool to anchor new concept meanings into existing frameworks (Horton, McConney, Gall, Woods, Senn & Hamelin, 1993).

Concept mapping has been found to be one of the teaching-learning strategies which place the student at the centre of learning activities and involve them in their own knowledge construction, while the teacher remains a facilitator (Cheema & Mirza, 2013). The use of concept mapping is believed to enhance recall and memory and can improve learning if carried out during instructional processes (Freeman & Jessup, 2004; Buldu & Buldu, 2010). The use of concept maps for instructional purposes has grown significantly over the last three decades (Jones, Ruff, Snyder, Petrich & Koonce, 2012), and has been found to be a potent instructional tool in information processing and for promoting meaningful learning (Horton, et al. 1993).

Nesbit and Adesope (2006) state that "initiating learning activities with constructive concept maps leads to small, positive effects on comprehension and their use as activity closing summaries produces somewhat larger positive effects, which is attributed to greater 'learner involvement'".

According to Nesbit and Adesope (2006) and Willis and Miertschin (2006) pictures and visual learning may help students to retrieve prior knowledge about the concept and therefore can be used to imbed the knowledge and enhance retrieval. Concept maps take ideas and pictures, which radiate out from a central concept, capturing a specific topic in a non-linear fashion through incorporating graphics and colours (Budd, 2004). Thus tapping into visual learning and connecting with students whose learning style is not as well served by linear, text-based materials.

Concept maps are believed to enhance memory (Freeman & Jessup, 2006) and when constructing concept maps it engages the student with the content, whereby they analyse their already existing knowledge structures and ideas and then integrate new knowledge with what they already know (Willis & Miertschin, 2006). Therefore, viewing or constructing concept maps in conjugation with text or spoken lessons may facilitate memory retention (Nesbit & Adesope, 2006). To adapt practices that encourage meaningful learning, it seems evident that teachers must also seek to learn ways in which subject matter can be taught meaningfully, by using knowledge representative systems that are useful in classroom settings.

Students registered for the Post Graduate Certificate in Education (PGCE) at our institution need to do action research during their seven weeks of Work Integrated Learning (WIL) and submit their research report as an exam equivalent at the end of the year. After various informal discussions with practicing Natural Sciences teachers it became clear that secondary school students are flooded with overwhelming terms and knowledge without constructing and connecting concepts to develop a framework which links content together in a concept building process. Only a few of these practicing teachers indicated that they utilise concept maps as a teaching-learning strategy. One of the PGCE students thought it worthwhile to investigate the role of concept mapping as a teaching learning strategy in Natural Sciences classrooms in order to view what implications the utilization of concept maps may have on the academic achievement of these students.

Research questions

The study addressed the following questions:

- Do Grade 8 students use concept mapping as a learning-strategy in Natural Sciences?
- Does the academic achievement differ between a Grade 8 control group (not taught with concept maps) and a Grade 8 experimental group (taught with concept maps)?
- What are the students' opinions on the role of concept mapping on their academic achievement when utilized in the classroom by their Natural Sciences teacher during the teaching-learning process?
- What are the students' opinion on the role of concept mapping on their academic achievement when they utilize concept maps while preparing for a class test?

RESEARCH DESIGN AND METHODOLOGY

A quasi-experimental design was undertaken, whereby groups and their participants are not assigned randomly due to already constructed class groups being present in the school (Creswell, 2005). Permission to carry out the research was given by the school principal. Students and their parents were informed about the study and their permission to allow their children to participate was requested. It was emphasised to all the parties involved that participation would be voluntary and that complete confidentiality would be maintained.

Two Grade 8 Natural Sciences classes were assigned to the study by a school in Gauteng. The study was conducted over a seven week period where two Grade 8 classes (class 8.1 and 8.6) were assigned to the study, one class was randomly chosen as the control group (class 8.1) and the other as the experimental group (class 8.6). There were 24 students in each of these two groups.

On day one both groups were given a questionnaire based on concept mapping to establish whether the students utilize concept mapping as a learning strategy. An assessment task as a ‘pre-test’ on the topic ‘scientific investigation’ was then given to both groups. On day two the students from the experimental group were taught how to construct a concept map. The next three days both groups were taught on the current topic which correlated with the prescribed curriculum. The experimental group was taught through the construction of a concept map and were asked to learn and study with the aid of the concept map. The control group was taught using the ‘traditional teaching strategy’ and were asked to learn and study the topic without the use of concept maps.

During the next class both groups did an assessment task (as a post-test) based on the topic ‘scientific investigations’. The control group was then given a presentation on concept mapping and the construction thereof to avoid any bias that might have arisen. During the next few weeks both groups were taught with the aid of concept mapping as a teaching-learning strategy. The lessons would start with the construction of a concept map of what was already known by the students on each topic. Throughout the instruction of the topic, concepts and ideas were incorporated and built onto the existing concept map with labelled lines linking the various ideas. During this process the map was analysed, discussed and any misconceptions were addressed. Each completed map was taken down by the students or integrated into their maps, i.e. building on concepts instead of stifling students with overwhelming knowledge collections.

The experimental group completed a second questionnaire related to their stance and opinions towards the use of concept mapping as a teaching-learning strategy. This post-test questionnaire comprised of two parts. Section A investigated the participants’ stances towards the use of concept mapping as a teaching-learning strategy while Section B investigated the students’ opinions towards the use of concept mapping as a teaching-learning strategy in the Natural Sciences classroom.

RESULTS

The results from the questionnaire based on the role that concept mapping already played in the students’ learning strategies, such as studying strategies and classroom strategies are indicated in Table 1 for the experimental group and Table 2 for the control group. The percentages of students in both groups using concept mapping as a study strategy and to prepare for the exams are relatively high (61% to 78%). However, the percentages in both groups using concept mapping as a note taking strategy in the class, to convert their class notes into concept maps and to understand and solve problems are quite low (9% to 39%).

The mean score for the participants of the control group in the assessment task based on the topic ‘scientific investigations’ as the pre-test was 54% whereas their mean score for post-test was 71%. The mean score for the participants of the experimental group in the pre-test assessment was 59% whereas their mean score for the post-test was 80%. Thus a marginally higher increase of 4% in the experimental group’s score compared to that of the control group was noticed.

Table 1. Utilisation of concept mapping (experimental group)

	Yes	No
I use concept mapping as a study strategy for Natural Sciences	61%	39%
I use concept mapping to prepare for Natural Sciences exams	65%	35%
I use concept mapping as a note taking strategy in my Natural Sciences class	30%	70%
I convert my Natural Sciences class notes into concept maps	22%	78%
I use concept mapping to understand and solve problems in Natural Sciences	39%	61%

Table 2. Utilisation of concept mapping (control group)

	Yes	No
I use concept mapping as a study strategy for Natural Sciences	61%	39%
I use concept mapping to prepare for Natural Sciences exams	78%	22%
I use concept mapping as a note taking strategy in my Natural Sciences class	26%	74%
I convert my Natural Sciences class notes into concept maps	9%	91%
I use concept mapping to understand and solve problems in Natural Sciences	30%	70%

The data from Section A of the post-test questionnaire showed that 52% of the students from the experimental group preferred the traditional teaching-learning strategy, 26% preferred concept mapping and the remaining 22% preferred a combination of the two strategies. Table 3 is reflecting the data of Section B of the post-test questionnaire dealing with the opinions students from the experimental group have about concept mapping as teaching-learning strategy. The most prominent difference is between the students who agreed (78%) with the statement *I enjoy Natural Sciences class when my teacher uses concept mapping to construct and link new knowledge to existing knowledge* compared to the students who disagree (22%) with this statement.

Table 3. Opinions about concept mapping as teaching-learning strategy (experimental group)

	SA*	A*	D*	SD*
I believe that concept mapping is an essential tool in learning Natural Sciences content	13%	31%	52%	4%
I feel all students can benefit from using concept mapping in learning Natural Sciences	4%	44%	52%	0%
I am eager to use concept mapping in studying for Natural Sciences tests	22%	26%	43%	9%
I enjoy Natural Sciences class when my teacher uses concept mapping to construct and link new knowledge to existing knowledge	35%	43%	22%	0%
Using concept mapping as a study strategy when studying Natural Sciences, increase my likeliness to achieve well academically	13%	39%	22%	26%

* SA – Strongly agree, A – Agree, D –Disagree, SD –Strongly disagree

DISCUSSION AND CONCLUSION

The pre-test questionnaire for both groups indicated that only a few students used the content mapping strategy to construct concept maps on their own in class during lessons, while many participants used a concept mapping strategy in studying and preparing for exams. Students like to know exactly which ideas or knowledge is needed to be learned (Cheema & Mirza, 2013) and therefore they indicated that they enjoy the strategy where the teacher facilitates (during the construction of the map) specific ideas and knowledge of what is needed to be known for assessment. Therefore, teachers should consider teaching with concept maps as one of their teaching-learning strategies, but using other strategies (investigations, experiments, etc.) along with the concept mapping strategy may yield even more beneficial results.

Having positively responded to concept mapping construction in class by the teacher and knowing that students like to know exactly which ideas or knowledge is needed to be learned (Cheema & Mirza, 2013), we can perhaps deduce that students enjoy the concept map strategy lessons because the teacher facilitates (during the construction of the map) specific ideas and knowledge of what is needed to be known out of the text material or lesson. According to Willis & Miertschin, 2006) the process of constructing a concept map engages the student with the content which is an active learning strategy that can be used during class instead of the traditional ‘chalk and talk’ strategy. Taking this into account we can deduce that the students responded well due to the active involvement they enjoyed when constructing concept maps in class. We can further find this response to be promising in that the students are in a place where they are exploring a heuristic strategy of teaching-learning (Novak & Gowin, 1984). According to Buldu and Buldu (2010) students prefer improving their learning in class to wanting to improve their grade-based achievement. This positive response to group map construction and facilitation engages students in an active interaction situation and out of the traditional ‘chalk and talk’ environment.

Yahaya (2010) found that although it is reasonably easy to persuade students that they will benefit from new learning skills, since they need to improve, it is more difficult to motivate average students to change their study strategies since they are already ‘getting by’ with techniques they use. This could be seen in the response to not being eager to use concept mapping in studying for Natural Sciences tests, but then a majority responded that they believe using concept mapping as a study strategy when studying Natural Sciences, increased their likeliness to achieve well academically. They need time and practice in class before they can master the skill to confidently construct a concept map alone.

This study would have bided well with a larger selection group such as all Grade 8 classes in the school participating in the study. Random selection of the participants in the groups would strengthen statistical results and may ensure proper selection for experimental and control groups, where students in the control group have zero to a minimum conversance with concept mapping.

Acknowledgement

I would like to acknowledge the valuable input of Ms Priest who worked on this project while she was doing her school practicum. In addition, my sincere gratitude goes to the department of Science and Technology Education at the Faculty of Education of the University of Johannesburg for the financial support to attend the ESERA conference.

REFERENCES

Ausubel, D.P. (1968). *Educational psychology: A cognitive view.* New York: Holt, Rinehart and Winston.

Budd, J.W. (2004). Mind maps as classroom exercises. *Journal of Economic Instruction,* 35(1), 35-46.

Buldu, M. & Buldu, N. (2010). Concept mapping as a formative assessment in college classrooms: measuring usefulness and student satisfaction. *Procedia Social and Behavioral Sciences,* 2(2), 2099-2104.

Cheema, A.B. & Mirza, M.S. (2013). Effect of concept mapping on students’ academic achievement. *Journal of Research and Reflection in Education,* 7(2), 125-132.

Creswell, J.W. (2005). *Educational research: planning, conducting and evaluating Quantitative and qualitative research*. 2nd Ed. New Jersey: Pearson.

Freeman, l.A. & Jessup, L.M. (2004). The power and benefits of concept mapping: measuring use, usefulness, ease of use, and satisfaction. *International Journal of Science Education,* 26(2), 151-169.

Horton, P.B., McConney, A.A., Gall, M., Woods, A.L., Senn, G.J. & Hamleon, D. (1993). An investigation of the effectiveness of concept mapping as an instructional tool. *Science Education,* 77(1), 95-111.

Jones, B.D., Ruff, C., Snyder, J.D., Petrich, B. & Koonce, C. (2012). The effects of mind mapping activities on students’ motivation. *International Journal for the Scholarship of Teaching and Learning,* 6(1), 1-21.

Nesbit, J.C. & Adesope, O.O. (2006). Learning with concept and knowledge maps: a meta-analysis. *Review of Educational Research,* 76(3), 413-448.

Novak, J.D. & Gowin, D.B. (1984). *Learning how to learn.* New York: Cambridge University Press.

Willis, C.L. & Miertschin, S.L. (2006). Mind maps as active learning tools. *Journal of Computing Sciences in Colleges,* 21(4), 266-272.

Yahaya, A. (2010). Information processing and its implication to teaching and learning. Unpublished, Faculty of education: University Technology Malasia.

THE ELECTRON GAS MODEL AS AN INTRODUCTION TO ELECTRICITY IN MIDDLE SCHOOL SCIENCE

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Abstract: Understanding the basic concepts of electricity represents a major challenge to most pupils in secondary science education. In particular, most learners do not succeed in developing an adequate understanding of "voltage". Instead, students usually reason exclusively with current and resistance and often see voltage as a property or component of an electric current. According to the current state of research in physics education, the introduction of voltage as a potential difference can be considered to be very promising. By equating the electric potential with the electron gas pressure inside a wire, the electron gas model seeks to build on these research findings and give students a qualitative but robust conception of the electric potential. Similarly to DiSessa (1993), the idea is to achieve conceptual change by building on students' prior knowledge regarding air pressure. In the electron gas model, voltage as potential difference is hence understood as an electric pressure difference across a resistor in the electric circuit that is as much the cause for an electric current as air pressure differences are the cause for an air flow. In a first step, the electron gas model was tested and evaluated in one-to-one teaching interviews with nine grammar school pupils in year 6 who never had a physics lesson before. It was found that the electron gas model including its underlying concepts such as the air pressure analogy was widely accepted and understood by the students. In particular, pupils could easily link their everyday experiences with air pressure (e.g. air pumps, syringes and bicycle tires) to the concept of electric pressure and subsequently developed an intuitive understanding of voltage as a pressure difference and cause of an electric current. This paper presents key findings from the teaching interviews and gives a short introduction to the main ideas of the subsequently developed teaching concept.

Keywords: conceptual understanding, teaching concept, electricity, potential, voltage

INTRODUCTION

Despite several years of science education, many students leave secondary school without having developed an adequate understanding of the basic physical concepts of electric circuits. Voltage in particular seems to represent a major challenge to most pupils in secondary school science as it is often seen as a property or component of an electric current rather than an independent physical quantity (Rhöneck, 1986). As the electric current seems to dominate students' understanding of electric circuits, they often fail to realise that voltage is not a property of the electric current, but the cause of it. While textbooks historically introduced electricity based on the concepts of electric potential and potential difference, explanations of electricity in textbooks nowadays mainly relate to the concepts of current and voltage. This seems rather odd as voltage by definition refers to a potential difference and one would therefore assume that any deeper understanding of the concept of voltage presupposes an understanding of the electric potential (Herrmann & Schmälzle, 1984, p.477). Research in physics education seems to back this view as it suggests that today's approach to teaching electricity with its focus on current and sometimes voltage rather than potential difference unnecessarily hampers a deeper understanding of electric circuits. The introduction of electricity based on potential differences, however, can be considered to be very promising according to numerous research findings (Schumacher & Wiesner, 1997; Gleixner, 1998; Clement & Steinberg, 2002, p.417). Examples of such approaches include the “flat water circuit analogy with a double water column” as shown in Figure 1 (Schwedes, Dudeck & Seibel, 1995, p.35) and the “stick model” developed in Munich (Gleixner, 1998) as illustrated in Figure 2. In both teaching concepts, the visual representation of the potential has proven to be an important factor for the learning success as it facilitates the build-up of a mental model of the electric potential (Schwedes, Dudeck & Seibel, 1995, p.35; Gleixner 1998, p.70).

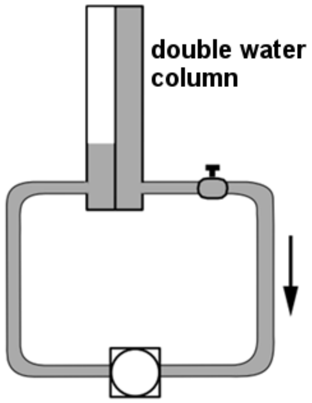

Figure 1. The flat water circuit analogy with a double water column visualises the potential difference using water columns.

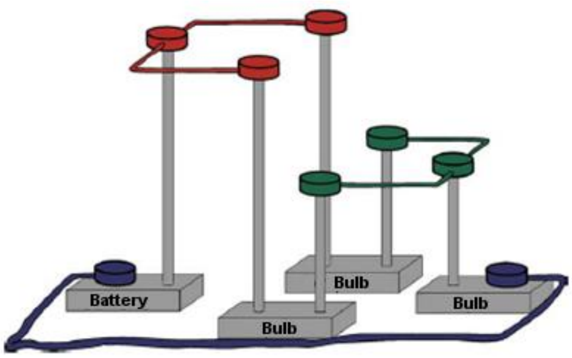

Figure 2. In the stick model, the electric potential is visualised by sticks with different heights.

THE ELECTRON GAS MODEL

Against the background that students usually reason exclusively with current and resistance while failing to develop and adequate understanding of voltage (Rhöneck, 1986), the objective of the electron gas model is to give students a qualitative but robust conception of the electric potential in order to enable them to effectively analyse electric circuits. Similarly to DiSessa (1993), the electron gas model seeks to achieve conceptual change by building on students’ prior knowledge, in this case their intuitive air pressure concept as a qualitative, low-abstraction prototype of the electric potential in conducting wires. It is important to note that we are not talking about the physical pressure concept in the technical sense of a state variable here, but an intuitive prototype concept of “pressure” in the sense that compressed air tries to push itself out of a container, e.g. based on everyday life experiences with air pumps, bicycle tires or air mattresses.

As a first step, it is hence discussed that air always flows from areas of high pressure to areas of low pressure and that air pressure differences are the causal reason for an air flow in the first place. A dense fabric cushion impeding the air flow is then used in order to prepare students for the idea of electric resistors. Air pressure hence corresponds to the electric potential, air pressure difference to voltage, air flow to current and a dense fabric cushion impeding the air flow to an electric resistor.

As a next step, the electron gas model proposes that electrons are always present in every wire in the form of tiny, freely mobile particles. These electrons form a compressible electron gas that spreads evenly across a wire as the electrons are negatively charged and therefore repel each other. The battery’s role in an electric circuit is to maintain a certain electron density in the wires directly attached to its terminals. A high electron density in the wire attached to the negative terminal corresponds to a high electric pressure and thus high electric potential. A low electron density in the wire attached to the positive terminal on the other hand corresponds to a low electric pressure and thus a low electric potential. In the electron gas model, voltage as potential difference can hence be understood as an electric pressure difference across a resistor that is as much the cause for an electric current as air pressure differences are the cause for air flow.

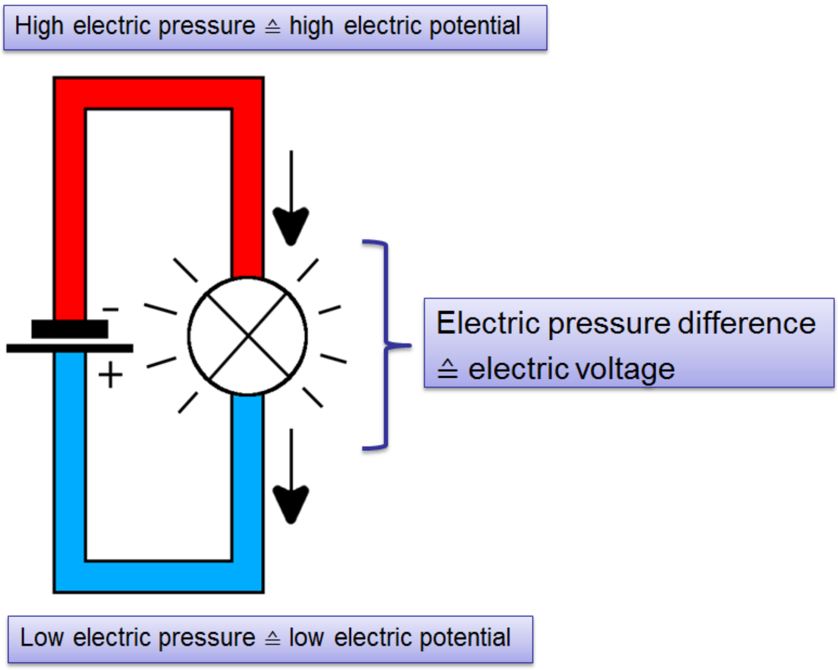

Figure 3. Electric pressure difference (=voltage) across a light bulb in a simple electric circuit.

A big advantage of the electron gas model is that it is based on everyday experiences with pressure in compressed air and hence only requires an intuitive air pressure concept. In contrast, water is often perceived as an incompressible fluid by learners, which makes it difficult for them to develop an adequate pressure concept necessary to understand the popular closed water circuit analogy. In the electron gas model, on the other hand, the proportional relationship between electron density and electric pressure is clear to most students and can also be easily visualised in established circuit diagrams. The use of an external model thus becomes unnecessary, which reduces the students' cognitive load and avoids potential transfer problems (cf. Kircher, 1984).

Contrary to popular belief, different parts of an electric circuit are indeed differently charged as suggested by the electron gas model. The slight differences are a result of surface charges, which make the electric field that drives the homogeneously distributed conduction electrons inside the wire (Walz, 1985). The reason why most people have never heard of surface charges in this context is that the amount of surface charges is almost negligible compared to the amount of conduction electrons inside the wire (Muckenfuß & Walz, 1997). However, at around 10,000 volts it is possible to detect the electrostatic effects of surface charges in a simple electric circuit as described in Chabay & Sherwood (2011). For a more thorough discussion of the physical background of the electron gas model, please refer to Burde et al. (2014).

KEY FINDINGS FROM THE TEACHING INTERVIEWS

In contrast to Clement & Steinberg (2002), a lot of effort was put in finding an intuitive visualisation of the electron gas model given the importance of visual representations for the build-up of a robust conception of the electric potential. A first draft of a teaching concept based on the electron gas model hence contained four different representations (see Figure 4) and was evaluated in one-to-one teaching interviews with nine grammar school pupils in year 6, who never had a physics lesson before. Each teaching interview was about two hours long.

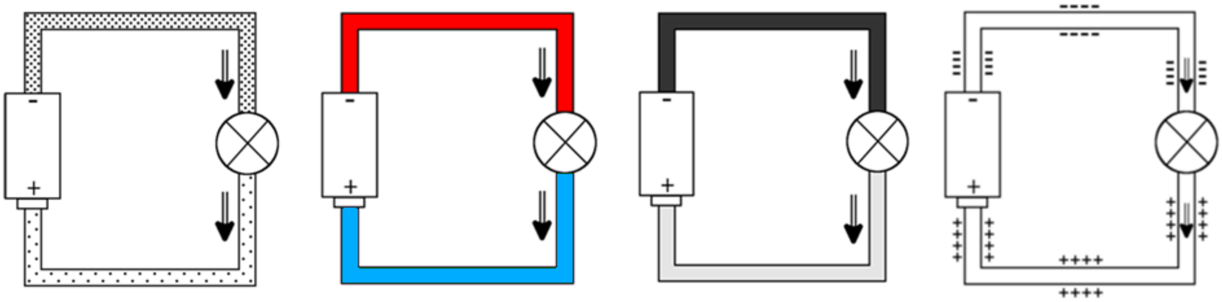

Figure 4. Different visual representations of the electric potential in the electron gas model.

Most favoured by the pupils was the dot-density representation closely followed by the colour representation, whereas the greyscale representation and the representation using plus-and-minus-symbols were considered to be least helpful. However, when asked to draw in the electric potential themselves, most pupils used the colour representation rather than the dot-density representation as colour coding proved to be far more practical than drawing hundreds of dots in a circuit diagram. Apparently, the students had no difficulty in switching between the dot-density and the colour representation.

More importantly, however, the electron gas model and its underlying concepts such as the air pressure analogy and the idea of mutually repelling electrons in wires were widely accepted and understood by the students in the first part of the teaching interview. In particular, pupils could easily link their everyday experiences with air pressure (e.g. with air pumps, syringes and bicycle tires) to the concept of electric pressure in a wire and subsequently developed an intuitive understanding of voltage as a pressure difference and cause of an electric current. Given that most learners do not succeed in developing an adequate understanding of “voltage” in traditional teaching concepts, this can be considered to be a very promising result.

The second part of the teaching interview was aimed at discovering potential learning difficulties that might occur in a teaching concept based on the electron gas model. While the basic ideas of the electron gas model itself proved to be relatively easy to understand, a number of new as well as known misconceptions particularly in regard to batteries and resistors could be identified. A battery was often seen by pupils as a source of constant current rather than constant voltage which led to a number of learning difficulties regarding the current and electric pressure in electric circuits. For example, pupils failed to realise that a battery maintains a certain electric pressure in the wires attached to its terminals and thought instead that the electric pressure in these wires depended on their length or physical size or the resistor used in the electric circuit (see Fig.5). Other students thought that in a parallel circuit, all areas of equal electric pressure had to have the same electric current. In other words, they could not distinguish clearly between the electric pressure concept and the electric current. Many students also held the widespread misconception that a battery stores electrons like an oil barrel and that these electrons leave the battery at one terminal and flow through the different circuit elements one after another – a misconception commonly referred to as sequential reasoning (Closset, 1984), which also prevents students from viewing an electric circuit as a system. Resistors also caused a number of learning difficulties, e.g. pupils confused the resistance value with the physical size of a resistor or even thought that a resistor would consume the electrons flowing through it.

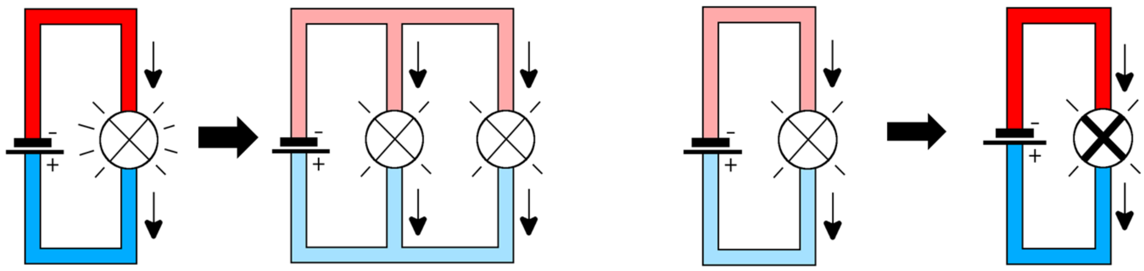

Figure 5. New misconceptions: The electric pressure decreases if the length of the wire is increased, e.g. by connecting a light bulb in parallel, since the electrons then have more space to spread out (left). If the resistance is increased, the electrons "pile up" in front of the resistor, which makes the electric pressure difference increase (right).

THE TEACHING CONCEPT

Based on the findings of the teaching interviews and the observed learning difficulties in particular, a teaching concept including appropriate teaching resources was developed. The main objective of the teaching concept is to give students a qualitative but robust conception of the physical quantities "voltage", "current" and "resistance". In contrast to other teaching concepts, a lot of emphasis is initially placed on helping students develop an intuitive understanding of the electric potential as an "electric pressure" in order to then introduce voltage as an electric pressure difference that drives the electric current through resistors. In order to give students an adequate conception of "electric pressure", the teaching concept starts with a brief discussion of electrostatics and air pressure.

Electrostatics

In a brief introduction to electrostatics, students learn that conductors, such as metals, can be negatively or positively charged and that two oppositely-charged objects attract each other while two objects with the like charge repel each other. Furthermore, they learn that the reason why objects are electrically charged is a lack or an excess of electrons, which can almost move freely in metals like copper while the atomic core remains stationary.

Pressure differences cause air flows

Based on the students' everyday experiences e.g. with air-pumps and air mattresses, it is then discussed that an air flow is always the result of a pressure difference and that it is absolutely necessary to differentiate between pressure and pressure difference. By blowing air through a scarf or a towel, students then learn that the thicker a piece of cloth is, the more it obstructs the air flow in order to prepare students for the concept of electrical resistance.

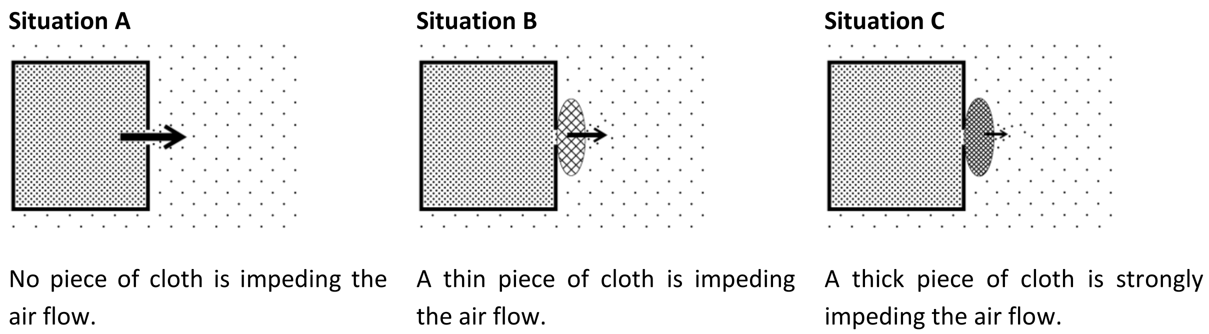

Figure 6. Pressure differences are the causal reason for air flow while a piece of cloth impedes air flow.

Battery, electric pressure and voltage

In this unit, the idea of pressure differences as the driving force for an air flow is transferred to electric circuits. Based on the idea that electrons can move just as freely in the wire as air particles can move in a tube, it is postulated that a battery causes a high electric pressure in the wires attached to the negative terminal and a low electric pressure in the wires attached to the positive terminal. This electric pressure is initially visualised using the same dot-density representation used to illustrate air pressure, but is then swapped for the colour representation since colour coding has proven to be far more practical in real lessons and draws the students' attention to the electric pressure instead of the electric current. At the example of various open electric circuits, it is then emphasised that pressure and pressure difference are two different concepts and that the electric pressure in conductors is determined solely by the battery terminals and is not dependent on the length or size of the conductor. Similarly to weather maps, the potential is visualised using different colours: the more intense the red, the higher the electric pressure and the more intense the blue, the lower the electric pressure.

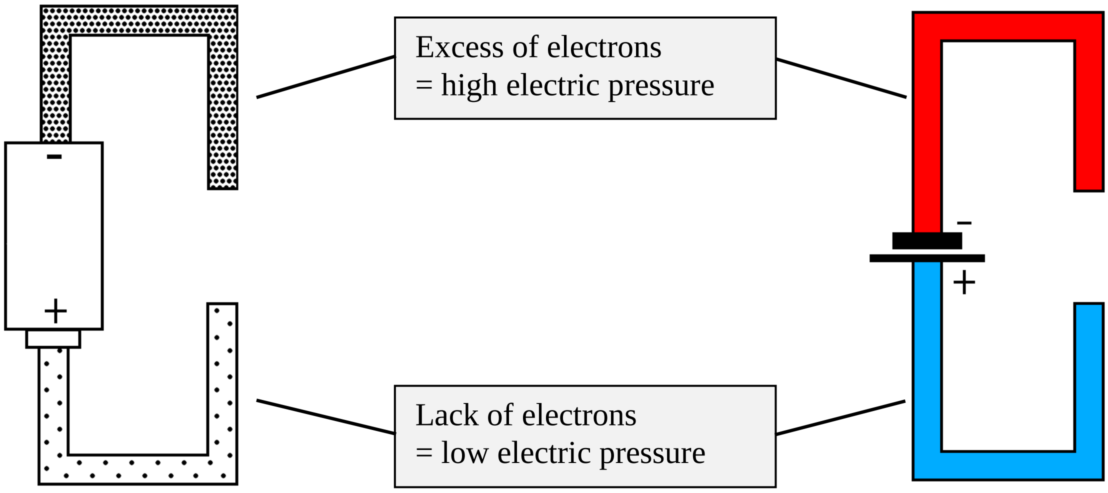

Figure 7. Dot-density representation (left) and colour coding (right) of the electric pressure (potential).

The electric current and resistance

After the concept of electric pressure has been established at the example of open circuits, electric pressure differences – in analogy to air pressure differences – are now introduced as the causal reason for electric currents in closed circuits. For this purpose, it is argued at the example of a simple electric circuit consisting of a battery and a light bulb that the electric pressure difference across the light bulb drives the electrons through the bulb, which subsequently lights up. For each electron flowing through the light bulb from high electric pressure to low electric pressure, the battery moves an electron from its positive to its negative terminal. As a result, the battery maintains the same electric pressure difference in the attached wires and hence also the across light bulb.

Similarly to the dense fabric cushion impeding the air flow, electrical resistance is initially introduced by simply stating that the higher the resistance, the more "difficult" it is for the electrons to move through the light bulb. A more in-depth explanation of electrical resistance referring to the collision of electrons with atomic nuclei is given at a later point. The effect of voltage and resistance on current is then discussed in order to work out the semi-quantitatively relationships "the higher the electric pressure difference across the bulb, the higher the electric current" and "the higher the resistance, the lower the electric current". The objective here is to give the students a semi-quantitatively understanding of the cause-effect relationships in electric circuits.

Semi-quantitative relationship between voltage and current

The higher the voltage (electric pressure difference), the higher the current.

Semi-quantitative relationship between resistance and current

The higher the resistance, the harder it is for electrons to pass through the light bulb and the smaller is hence the current.

Figure 8. Semi-quantitative relationship between current, voltage and resistance.

Parallel circuits

Parallel circuits can be easily understood using the electron gas model. Furthermore, they provide an excellent learning opportunity for students to help them distinguish clearly between the electric pressure concept and the electric current. As a first step, students have to learn that an (ideal) battery maintains the same electric pressure in the wires attached to its terminals at all times. In order to then analyse the electric current in a parallel circuit, students simply have to look at the electric pressure differences at the light bulbs and their resistance. As shown in Figure 9, the electric current through the two light bulbs with a low resistance on the left is 2 A while it is 1 A through the light bulb on the right, which has a higher resistance. The individual branch currents, which are a result of the electric pressure differences across the light bulbs, then sum up at each node of the parallel circuit.

In other words, the total current which the battery needs to supply, is directly determined by the branch currents, which are in turn determined by the pressure differences at and resistance of the light bulbs. Another advantage of colour coding lies in the fact that it makes it extremely easy for students to identify blubs in parallel: If two bulbs have the same adjacent colours, they are connected in parallel.

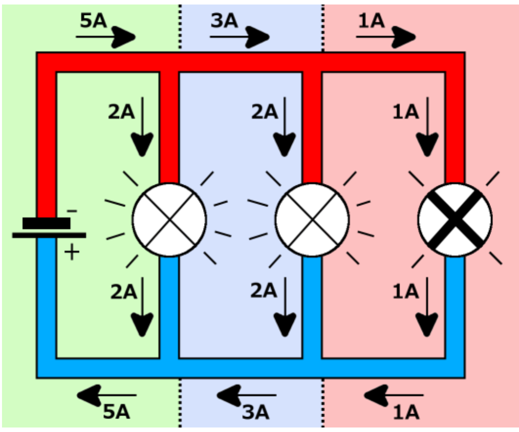

Figure 9. Parallel circuit with three light bulbs. The right bulb has a higher resistance than the other two.

Capacitors

By analysing capacitor charging and discharging, students are introduced to the concept of transient states and dynamic model thinking in order to prepare them for the analysis of series circuits. The idea behind transient states is that it takes some time for the electric pressure to reach a steady state in the whole circuit and that the steady state is only achieved gradually over so-called transient states. At the example of Figure 10, this can easily be explained.

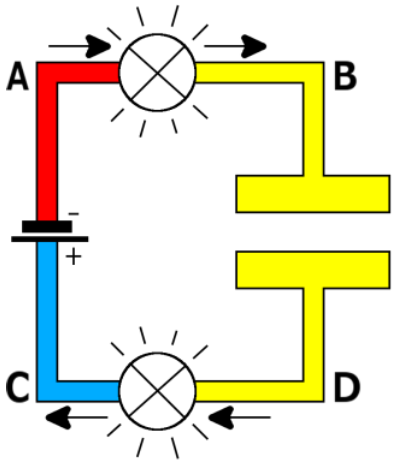

Figure 10. Transient state during capacitor charging.

Initially, we have a high electric pressure in section A and a low electric pressure in section C while we still have a normal electric pressure in section B and D. The reason is that no electron has flown through the light bulbs yet – they have only just started moving, which is why the bulbs are lit. During the transient state, electrons now flow from section A to section B (high electric pressure to normal electric pressure) and as a consequence the electric pressure in section B increases. At the same time, electrons flow from section D to section C (normal electric pressure to low electric pressure) and as a consequence the electric pressure in section D decreases. After the transient state of capacitor charging, the capacitor reaches the steady state, where the electric pressures on each side of the light bulbs have become aligned. Discussing capacitor charging and discharging can also help students overcome a number of common misconception, e.g. the belief that there are initially no electrons in wires, that the battery stores electrons as an oil barrel stores oil and that the electric current simply leaves the battery at the negative terminal in order to flow through the circuit step by step ("sequential reasoning").

Series circuits

Using the concept of transient states, a series circuit of a light bulb with a high resistance and a light bulb with a low resistance shall now be analysed step by step. Initially, when the battery is not yet connected, we have a normal electric pressure in all parts of the wire (yellow). Once the battery is connected, we have a high electric pressure in the top wire (red) and a low electric pressure in the bottom wire (blue). In the middle wire, we still have a normal electric pressure (yellow) since no electrons have flown through the light bulbs yet (transient state). At this point, we have the same electric pressure difference (=voltage) across both light bulbs, but since the top light bulb has a higher resistance than the bottom light bulb, fewer electrons flow into the middle wire than out of it. As a result, the electric pressure in the middle wire decreases so that the electric pressure difference increases at the top bulb and decreases at the bottom bulb. This makes the electron flow rates through the top and bottom bulbs more and more equal until they are identical. This state is called the steady state since both the electric pressure in the wires and the electric current in the circuit do not change any further.

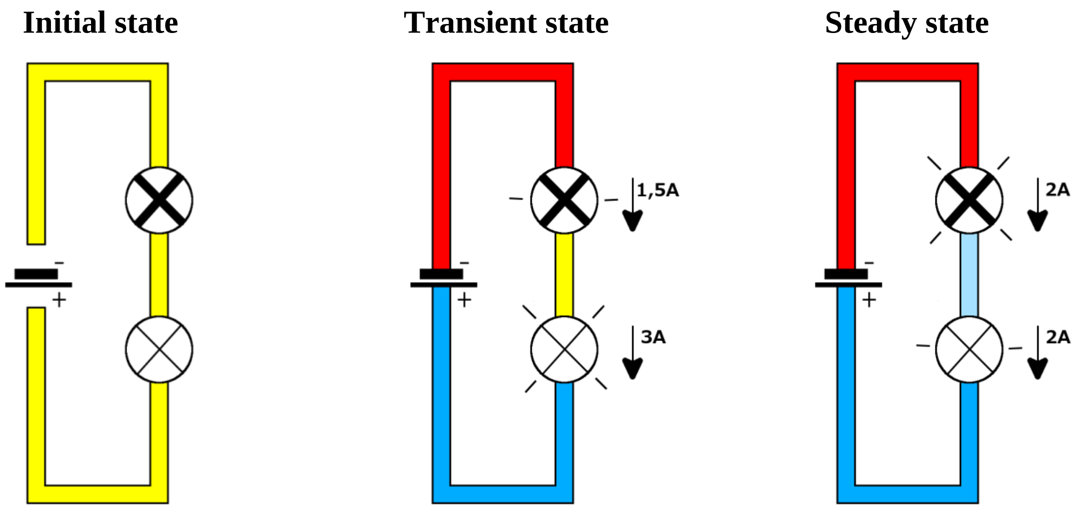

Figure 11. Step by step analysis of a series circuit with two different light bulbs.

Ohm’s Law and quantitative measurements

After a qualitative understanding of the basic concepts “voltage”, “current” and “resistance” has been established, students then learn about the quantitative relationship between these physical quantities using the definition of resistance R := V / I. For this purpose, the voltmeter and ammeter are introduced as measuring instruments and visualised as illustrated in Figure 12. In order to determine the pressure difference, the voltmeter is equipped with two “sensor cables”, which measure the electric pressure before and after a resistor. By not colouring in these “sensor cables”, it is clearly visualised that they are part of an external measuring instrument and – at least at this stage – not part of the actual electric circuit. As can also be seen in Figure 12, the wide “electron tubes” that have so far been used to illustrate wires, are now dropped for conventional circuit diagrams.

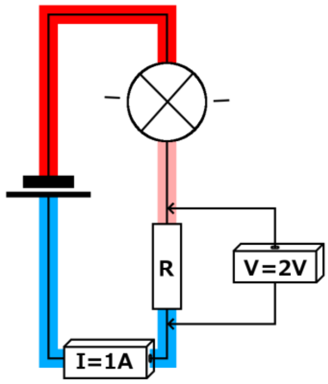

Figure 12. Illustration of voltmeters and ammeters in a simple circuit.

In the teaching concept, Ohm’s law is treated as an exception rather than the rule since most resistors do not have a fixed resistance value. Since the students are already familiar with the qualitative relationship between the physical quantities “voltage”, “current” and “resistance”, the known qualitative relationship is transformed into a quantitative relationship as a last step of the teaching concept.

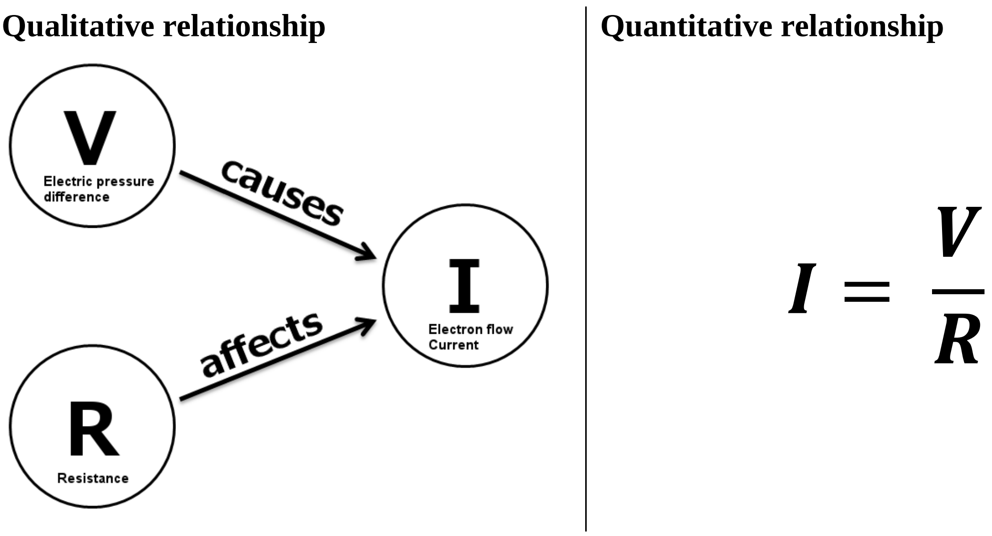

Figure 13. Transition from a qualitative to a quantitative relationship of the physical quantities current, voltage and resistance.

CONCLUSION AND OUTLOOK

In summary it can be said that the electron gas model has proven to be a promising approach to teaching electricity in secondary schools. The conducted teaching interviews show that students generally accept and understand all basic concepts and ideas behind the teaching concept and develop a solid understanding of “voltage” as an electric pressure difference that makes the electrons flow through light bulbs. This is a particularly promising result given the relatively short time frame for the teaching interviews and that many students fail to develop an adequate concept of “voltage” in traditional teaching concepts.

Based on the findings of the teaching interviews, a teaching concept including various resources for teachers and students was developed and is currently being evaluated in the classroom. Using a pre- and post-test design, it is planned to compare the learning progress of traditionally taught classes with physics classes that were taught using the new teaching concept. The learning progress is measured using Urban-Woldron’s valid and reliable electricity test (cf. Urban-Woldron, 2013). Furthermore, it is planned to conduct a survey with some of the 25 teachers around Frankfurt who have agreed to participate in our study in order to get some qualitative feedback on their experiences with the new teaching concept.

REFERENCES

Burde, J.-P., Wilhelm, T. & Wiesner, H. (2014). Das Elektronengasmodell in der Sekundarstufe I. In: *PhyDid-B - Didaktik der Physik – Frühjahrstagung Frankfurt 2014*, www.phydid.de

Chabay, R. W. & Sherwood, B. A. (2011). *Matter & Interactions*. Hoboken N.Y.: Wiley.

Clement, J. J. & Steinberg, M. S. (2002). Step-Wise Evolution of Mental Models of Electric Circuits: A „Learning-Aloud“ Case Study. In: *The Journal of The Learning Sciences,* 11(4), 389-452.

Closset, J. L. (1984). Woher stammen bestimmte „Fehler” von Schülern und Studenten aus dem Bereich der Elektrizitätslehre? Kann man sie beheben? *Der Physikunterricht,* 18(2), 21–31.

DiSessa, A. (1993). Toward an Epistemology of Physics. In: *Cognition and Instruction,* 10, 105 – 225.

Gleixner, C. (1998). *Einleuchtende Elektrizitätslehre mit Potenzial*, Dissertation LMU München.

Herrmann, F. & Schmälzle, P. (1984). Das elektrische Potential im Unterricht der Sekundarstufe I. In: *MNU*, 37(8), 476-482.

Kircher, E. (1984). Analogmodelle für den elektrischen Stromkreis. In: *Der Physikunterricht,* 18(2), 46 – 60.

Muckenfuß, H. & Walz, A. (1997). *Neue Wege im Elektrikunterricht*: *zweite überarbeitete Auflage*. Köln: Aulis Verlag Deubner.

Rhöneck, C. v. (1986). Vorstellungen vom elektrischen Stromkreis und zu den Begriffen Strom, Spannung und Widerstand. In: *Naturwissenschaften im Unterricht – Physik,* 34(13), 108-112.

Schumacher, M. & Wiesner, H. (1997). Erprobung des Potentialansatzes in der Elektrizitätslehre in Form einer Akzeptanzbefragungssequenz. In: *Vorträge Physikertagung*, DPG Tagung 1996, 573-578.

Urban-Woldron, H. (2013). Das Verständnis in der Elektrizitätslehre überprüfen. In: Bernholt, S. (ed.): *Inquiry-based learning - Forschendes Lernen, GDCP Jahrestagung in Hannover 2012*, 33, 209 – 211.

Walz, A. (1985). Fields that accompany currents. In: Duit, R., Jung, W. & Rhöneck, C.v.: *Aspects of Understanding Electricity: Proceedings of an International Workshop*, 403-412.

USING CLUSTER ANALYSIS TO STUDY THE MODELING ABILITIES OF ENGINEERING UNDERGRADUATE STUDENTS: A CASE STUDY

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Abstract: In this contribution we discuss the application of a quantitative, non-hierarchical clustering method to make sense of the answers that 120 engineering undergraduates students at the University of Palermo, Italy, gave to four open-ended questions on the meaning of the modeling processes in Science. We will show that the use of non-hierarchical analysis allows us to easily separate students into groups that can be recognized and characterized by common traits in students' answers without any prior knowledge on the part of the researcher of what form those groups would take (unbiased classification).

Keywords: Cluster Analysis; Physics Education Research; Modeling

INTRODUCTION

Extensive qualitative research involving open answer questionnaires has provided instructors/teachers with tools to investigate their students' conceptual knowledge of various fields of physics. Some of these studies examined the consistency of students' answers in a variety of situations. Others looked at problems where the underlying physical systems are similar from the point of view of an expert. In recent years, some papers have tried to develop more detailed models of the consistency of students' reasoning, or to subdivide a sample of students into intellectually similar subgroups. Bao and Redish (2006) introduced model analysis as a framework for exploring the structure of the consistency of the application of student knowledge, by separating a group of students into intellectually similar subgroups.

The problem of taking a set of data and separating it into subgroups where the elements of each subgroup are more similar to each other than they are to elements not in the subgroup has been extensively studied through the statistical method of Cluster Analysis (ClA). ClA can separate students into groups that can be recognized and characterized by common traits in their answers, without any prior knowledge of what form those groups would take (unbiased classification).ClA, introduced in Psychology by R.C. Tyron in 1939, has been the subject of research since the beginning of the 1960s, with its first systematic use by Sokal e Sneath in 1963. The application of techniques related to ClA is common in many fields, including Information Technology, Biology, Medicine, Archeology, Econophysics and Market Research. For example, in market research it is important to classify the key elements of the decision-making processes of business strategies as the characteristics, needs and behavior of buyers. These techniques allow the researcher to locate subsets or clusters within a set of objects of any nature. These have a strong tendency to be homogeneous "in some sense". The results of the analysis should reveal a high homogeneity within the group (intra-cluster), and high heterogeneity between groups (inter-clusters), in line with the criteria chosen.

In the literature concerning research in education, some studies using ClA methods are found. They group and characterize student responses by using open-ended questionnaires (Wittmann & Scherr, 2002; Fazio et al., 2012; Fazio et al., 2013) or multiple-choice tests (Ding & Beichner, 2009). A recent paper (Stewart et al., 2012) analyses the evolution of student responses to seven contextually different versions of two Force Concept Inventory questions, by using a model analysis for the state of student knowledge and ClA methods to characterize the distribution of students' answers. This paper shows that ClA methods are an effective way to examine the structure of student understanding and can produce significant subgroups of a data sample. The authors conclude that the ClA method is an effective mechanism for extracting the underlying subgroups in student data and that additional insight may be gained from a careful, qualitative analysis of clustering results. In fact, each cluster is characterized by means of a careful reading of the typical trends in the answers of the individuals that are part of the cluster. It is well known that there are inherent difficulties in the classification of student responses in the studies mainly involving open-ended questionnaires. In fact, the problem of quantifying qualitative data has been widely discussed in the literature for many years (Green, 2001), and it has been pointed out that, very often, a small or even unconscious researcher bias means that the categories picked out tend to find those groups of students that the researcher is already looking for. A recent paper (Hammer & Berland, 2014) points out that researchers "should not treat coding results as data but rather as tabulations of claims about data and that it is important to discuss the rates and substance of disagreements among coders" and proposes guidelines for the presentation of research that quantifies qualitative data. Another paper (Chi, 1997) discussed the need to describe the process of developing a coding scheme, by outlining that in the process of quantifying qualitative data, data means the qualitative records supplied by students and not the result of the coding scheme. If we call these records "raw data" we have to take into account that the data being quantitatively analyzed, which is obtained through the process of data reduction (Hammer & Berland, 2014) contained in the coding scheme, is biased by the subjective interpretation of researchers. It is important for this to be taken into account in the interpretation of the results of the subsequent quantitative analysis.

In this paper we start from a description of the data coding needed in ClA, in order to discuss the meanings and the limits of the interpretation of quantitative results. Then a method commonly used in ClA is described and the variables and parameters involved are outlined and criticized. The application of this method to the analysis of data from an open-ended questionnaire administered to a sample of university students and the related quantitative results is presented. In the last section we discuss the meaning of our results for the physics education researcher and outline some points of strength and limits.

METHODS

Data setting

Research in education that uses open-ended questions and is aimed at quantifying qualitative data usually involves the development of coding procedures. This requires an accurate reading of student answers in order to reveal (and then examine) patterns and trends, and to find common themes emerging from them. These themes are then developed in a number of categories, which can be considered the typical "answering strategies" put into action by the *N* students tackling the questionnaire items. Therefore, it is possible to summarize the whole set of answers given to the questionnaire into a limited number, *M*, of answering strategies, making the subsequent analysis easier. Through coding and categorization we produce a set of *M* data (the answering strategies) for each of the sample subjects (the *N* students doing the questionnaire). As a consequence, each subject, i, can be identified by an array, ai, composed of *M* components 1 and 0, where 1 means that the subject used a given answering strategy to respond to an item, and 0 means that he/she did not use it. Then, a *M* x *N* binary matrix (the "matrix of answers") modeled on the one shown in Table 1, is built. The columns in it show the *N* student arrays, a_i, and the rows represent the *M* components of each array, i.e. the *M* answering strategies.

Table 1. Matrix of data: the *N* students are indicated as S_1, S_2, …,S_N., and the *M* answering strategies as AS_1, AS_2, …, AS_M.

Strategy	*Student*			
	S_1	S_2	…	S_N
AS_1	1	0	…	0
AS_2	1	0	…	1
…	0	…	…	…
AS_M	0	1	…	0

For example, let us say that student S_1 used answering strategies AS_1, AS_2 and AS_5 to respond to the questionnaire questions. Therefore, S_1 column in Table 1 will contain the binary digit 1 in the three cells corresponding to these strategies, while all the other cells will be filled with 0.The matrix depicted in Table 1 contains all the information to describe the sample behavior with respect to the questionnaire items. However, it needs some elaboration in order to make this information understandable. ClA classifies subset behaviors in different groups (the clusters). These groups can be analyzed in order to deduce their distinctive characteristics and point out similarities and differences among them. ClA requires the definition of new quantities that are used to build the grouping, like the "similarity" or "distance" indexes. These indexes are defined by starting from the *M* x *N* binary matrix discussed above.In the literature the similarity between two elements*i* and *j* of the sample is often expressed by taking into account the distance, d_{ij}, between them (which actually expresses their "dissimilarity", in the sense that a higher value of distance involves a lower similarity). The distance index can be defined by starting from the Pearson's correlation coefficient. It allows the researcher to study the correlation between elements*i* and *j* if the related variables describing them are numerical. If these variables are non-numerical variables (as in our case, where we are dealing with the arrays a_i and a_j containing the binary coding of the answers of elements*i* and *j*, respectively), we propose a modified form of the Pearson's correlation coefficient, R_{mod}, similar to that defined by Tumminello et al. (2011) as,

$$R_{\text{mod}}\left(a_i,a_j\right)=\frac{p\left(a_i\cap a_j\right)-\dfrac{p\left(a_i\right)p\left(a_j\right)}{M}}{\sqrt{p\left(a_i\right)p\left(a_j\right)\left(\dfrac{M-p\left(a_i\right)}{M}\right)\left(\dfrac{M-p\left(a_j\right)}{M}\right)}} \qquad (1)$$

where $p(a_i)$ and $p(a_j)$ are the number of properties of a_i and a_j explicitly present in our elements (i.e. the numbers of 1's in the arrays a_i and a_j, respectively), *M* is the total number of properties to study (in our case, the possible answering strategies) and $p(a_i \cap a_j)$ is the number of properties common to both elements, *i* and *j* (the common number of 1's in the arrays a_i and a_j). By following eq. (1) it is possible to find for each student, *i*, the *N-1* correlation coefficients R_{mod} between him/her and the others students (and the correlation coefficient with him/herself, that is, clearly, 1). All these correlation coefficients can be placed in a *N* x *N* matrix that contains the information we need to discuss the mutual relationships between our students. The similarity between subjects *i* and *j* can be defined by choosing a type of metric to calculate the distance d_{ij}. Such a choice is often complex and depends on many factors. If we want two subjects, represented by arrays a_i and a_j and negatively correlated, to be more dissimilar than two positively correlated subjects (as is often advisable in research in education), a possible definition of the distance between a_i and a_j, making use of the modified correlation coefficient, $R_{mod}(a_i, a_j)$, is:

$$d_{ij}=\sqrt{2\left(1-R_{\text{mod}}\left(a_i,a_j\right)\right)} \qquad (2)$$

This function defines a Euclidean metric (Gower, 1966), which is required in order to use it for the following calculations. A distance d_{ij} between two students equal to zero means that they are completely similar, while a distance $d_{ij} = 2$ shows that the students are completely dissimilar. By following eq. (2) we can, then build a new *N* x *N* matrix , $\mathcal{D}$, containing all the utual distances between the students. The main diagonal of $\mathcal{D}$ is composed by 0s (the distance between a student and him/herself is zero). Moreover, $\mathcal{D}$ is symmetrical with respect to the main diagonal.

Clustering technique

In this paper we use a technique known as Non-Hierarchical Clustering (NH-ClA), that basically allows us to partition the data space into a structure known as a Voronoi diagram (a number of regions including subsets of similar data). Among the many NH-ClA algorithms, we use here the k-means, which was first proposed by MacQueen (MacQueen, 1967). In this method, the final result is a bi-dimensional Cartesian plane containing points that represent the students of the sample placed in the graph according to their mutual distances. As said before, for each student, *i*, we know *N* distances. It is, then, necessary to define a procedure to find two Cartesian coordinates for each student, starting from these *N* distances. This procedure consists in a linear transformation between a *N*-dimensional vector space and a 2-dimensional one and it is well known in the specialized literature as multidimensional scaling (Borg & Groenen, 1997). The starting point is the choice of the number of clusters one wants to populate and of an equal number of "seed points", randomly selected in the bi-dimensional Cartesian plane representing the data. The subjects are then grouped on the basis of the minimum distance between them and the seed points. Starting from an initial classification, subjects are transferred from one cluster to another or swapped with subjects from other clusters, until no further improvement can be made. The subjects belonging to a given cluster are used to find a new point, representing the average position of their spatial distribution. This is done for each cluster and the resulting points are called the cluster centroids. This process is repeated and ends when the new centroids coincide with the old ones. The spatial distribution of the set elements is represented in a two-dimensional Euclidean space, creating what is known as the k-means graph (see Figure 2).

NH-ClA has some points of weakness and here we will describe how it is possible to overcome them. The first involves the a-priori choice of the initial positions of the centroids. This can usually be resolved by repeating the clustering procedure for several values of the initial conditions and selecting those that lead to the minimum values of the distances between each centroid and the cluster elements. Furthermore, at the beginning of the procedure, it is necessary to arbitrarily define the number of clusters. A method widely used to decide if the number of clusters, *q*, initially used to perform the calculations is the one that best fits the sample element distribution is the calculation of the so-called Silhouette Function, *S*. (Rouseeuw, 1987).

Several values of the function S are calculated once a value of the number of clusters, *q*, is fixed:

- the individual value, $S_{k,i}(q)$, with $k=1, 2,..q$, for each student, *i*, of the sample. It gives a measure of how similar student *i*is to the other students in its own cluster Cl_k, when compared to students in other clusters. It ranges from -1 to +1; a value near +1 indicates that student *i* is well-matched to its own cluster, and poorly-matched to neighboring clusters. If most students have a high silhouette value, then the clustering solution is appropriate. If many students have a low or negative silhouette value, then the clustering solution could have either too many or too few clusters (i.e. the chosen number, *q*, of clusters should be modified).
- The average silhouette value in cluster Cl_k, $< S_k(q)>$, with $k=1, 2,..q$. It gives the average value of $S_{k,i}(q)$, calculated on all the students belonging to cluster Cl_k and it is a measure

of the density of the cluster. Large values of $< S_k(q)>$ are to be related to cluster elements being tightly arranged in the cluster *k*, and vice versa (Rouseeuw, 1987).

- The total average silhouette value, $< S(q)>$ for the chosen partition in *q* clusters. It gives the average value of $S_{k,i}(q)$, calculated on all the students belonging to the sample. Large values of $< S(q)>$ are to be related to well defined clusters (Rouseeuw, 1987). It is, therefore, possible to perform several repetitions of the cluster calculations (with different values of *q*) and to choose the number of clusters, *q*, that gives the maximum value of $<S(q)>$.

Once the appropriate partition of data in *q* clusters Cl_k (with $k = 1,..q$) has been obtained, as well as their related centroids, C_k, (i.e. the coordinates in the 2-dimensional space of the *q* points that represent the average positions of the cluster spatial distributions), it is possible to transform such coordinates in terms of the same variables that represent the students in the plane. In particular, for each centroid, C_k, we find an array b_k with the same number *M* of components of the array, a_i, that identifies a generic real student *i*, (i.e. the number *M* of answering strategies to the questionnaire) and composed, as a_i, by 0 and 1 values. b_k can be considered as the array representing a *virtual student* in cluster Cl_k. By considering the meaning of cluster Cl_k centroid, we could use the answering strategies contained in array b_k to make sense of the features of the clusterreal students.

A remarkable feature of array b_k, that can validate our idea to use the centroid to characterize the features of the cluster Cl_k real students, is that it contains 1 values exactly in correspondence to the answering strategies most frequently given by students belonging to Cl_k. In fact, since a centroid is defined as the geometric point that minimizes the sum of the distances between it and all the cluster elements, by minimizing this sum the correlation coefficients between the cluster elements and the centroid are maximized and this happens when each centroid has the largest number of common strategies with all the students that are part of its cluster.

It is worth noting that if some answering strategies are only slightly more frequent than the other ones all those with similar frequencies should be also considered. In order to analyze how well each centroid characterizes its own cluster Cl_k, we propose a coefficient, r_k, defined as the centroid *reliability,* that relates the cluster density to its dimension. It is calculated as follows:

$$r_k = \frac{\langle S_k(q) \rangle}{1 - \langle S_k(q) \rangle} \frac{1}{n_k} \quad (3)$$

where n_k is the number of students contained in cluster Cl_k and $< S_k(q)>$ is the average value of the *S-function* on the same cluster. High values of r_k indicate that the centroid characterizes well the cluster, as this happens for dense clusters or for clusters with a low number of students. In fact, considering two equally dense clusters, the one with a lower number of students involves smaller cluster dimensions, i.e. a lower variability of student properties.

Example of quantitative study

In this section we analyze the answer strategies to an open-ended questionnaire supplied by a sample of university students, using the techniques discussed above.

The questionnaire and the sample

The questionnaire is made up of four-items that focus on an understanding of the modeling concept (see Appendix). They are part of a more complex questionnaire, which has already been used, in previous research (Fazio et al., 2012). The selected four items refer to: I) the definition of a physics model, II) the subjects' beliefs about the representational modes of physics models, III) the main characteristics of models and IV) the student's beliefs about the modeling process. The questionnaire was administered to 124 freshmen of the Information Technology and Telecommunications Engineering Degree Course at the University of Palermo, during the first semester of the academic year 2013/2014. The students were given the questionnaire during the first lesson of general physics, before any discussion on the model concept had started.

Categorization of student answers

After the questionnaire had been submitted to our student sample, three researchers independently read the students' answers in order to identify the main characteristics of the different student records (the raw data). Then, they agreed to construct a coding scheme through the identification of keywords that were relevant for an understanding of these records. During the first meeting, the selected keywords were compared and contrasted, and then grouped into categories based on epistemological and linguistic similarities (for example, students that defined models as *simple phenomena* or *experiments* or *reproductions of an object on a small scale* have been put on the same category since the three definitions have been intended as giving a ontological reality to models.). These categories were also re-analyzed through the researchers' interactions with the data, and taking into account the existing literature about models and modeling (Grosslight et al., 1991; Van Driel & Verloop, 1999, Treagust et al., 2002; Pluta et al., 2011). As a third step, the researchers read the student records again and applied the new coding scheme, by assigning each student to a given category for each question. Given the inevitable subjectivity of the researchers' interpretations, the three lists were compared and contrasted in order to get to single agreed list. The inter-rater reliability of the analysis was good. Discordances between researcher lists were usually a consequence of the different personal decisions of the researchers to divide the student answers into a more or less restricted number of typologies. In some cases, discordances were due to different researcher interpretations of student statements. This happened 14 times when comparing tables of researchers 1 and 2, 9 times for researchers 2 and 3, and 12 times for researchers 1 and 3. Hence we obtained very good percentages of accordance (97%, or higher) between the analysis tables of each researcher pair. When a consensus was not obtained, the student answer was classified in the category "statement not understandable".

It is worth noting that very often the researchers' discussions while assigning each student to a given category produced a more refined definition of these categories. The complete list of 20 categories shared by researchers with respect to the four questions can be seen in Appendix A. As a result of the coding and categorization, we obtain a matrix like the one depicted in Table 1, where $N = 124$ and $M = 20$. This matrix of data represents a set of properties (the categories to which student answers have been assigned) for each subject (the student being analyzed).

RESULTS

All the clustering calculations were made using a custom software, written in C language. The graphical representations of clusters in both cases were obtained using the well-known MATLAB software.

In order to define the number q of clusters that best partitions our sample, the mean value of *S-function*, $<S(q)>$, has been calculated for different numbers of clusters, from 2 to 10 (see Figure 1). The figure shows that the best partition of our sample is achieved by choosing four clusters, where $<S(q)>$ has its maximum. The obtained value $<S(4)> = 0.62$ indicates that a reasonable cluster structure has been found (Struyf et al., 1997).

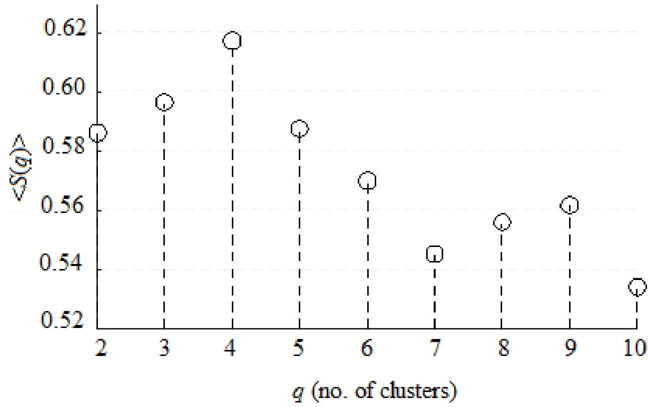

Figure 1. Average Silhouette values for different cluster partitions of our sample.

Figure 2 shows the representation of this partition in a 2-dimensional graph. The four clusters show a partition of our sample into groups made up of different numbers of students (see Table 2)

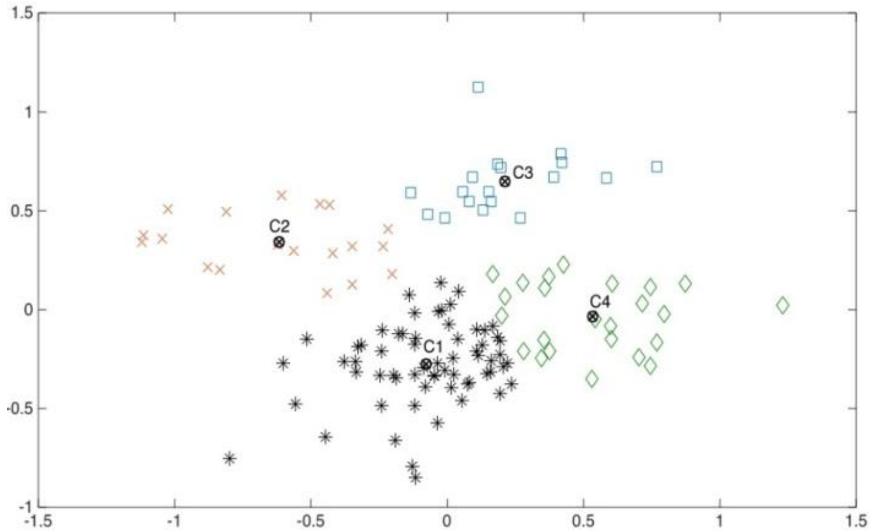

Figure 2. *K-means* graph. Each point in this Cartesian plane represents a student. Points labeled C_1, C_2, C_3, C_4 are the centroids.

The four clusters Cl_k $(k=1,...,4)$ can be characterized by their related centroids, C_k. They are the four points in the graph whose arrays, b_k, contain the answering strategies most frequently applied by students in the related clusters (see Table 2). The codesused refer to the answering strategies for the questionnaire items described in Appendix A. Table 2 also showsthe number of students in each cluster, the mean values of the *S-function* $<S_k(4)>$ $(k=1,..,4)$ for the four clusters andthe normalized reliability index r_k^{norm} of their centroids (in order to have comparable reliability values r_k, they have been normalized ($r_k^{norm}= [(r_k - <r_k>]/\sigma(r_k)$), where $<r_k>$ and $\sigma(r_k)$ are the mean value and the variance, respectively).

Table 2. An overview of the obtained results

Cluster centroid	C_1	C_2	C_3	C_4
b_k (Most frequently given answers)	1C, 2B, 3A, 4A	1B, 2B, 3E, 4A	1B, 2C, 3B, 4A	1C, 2C, 3B, 4B
Number of students	63	19	18	24
$<S_k(4)>$	0.60	0.62	0.75	0.56
r_k^{norm}	-0.92	-0.02	1.4	-0.46

We can see (from the value of $<S_k(4)>$) that cluster Cl_3 is denser than the others, and Cl_4 is the most spread out. Furthermore, the values of r_k^{norm} show that centroid C_3 best represents its cluster, whereas centroid C_1 is the least representative and characterizes less well the cluster.

DISCUSSION AND CONCLUSIONS

The four questions in our questionnaire mainly refer to: I) the definition of a physics model, II) the subjects' beliefs about ways of representing physics models, III) the main characteristics of models and IV) the subjects' beliefs about the modeling process. We have classified student answers into categories, also called answering strategies, that explain student reasoning strategies. Looking at our results, the four clusters identified are characterized by the related centroids and each centroid is represented by one array b_k, which describes the different answering strategies categorized for each question. These strategies are defined as follows: b_1: (1C, 2B, 3A, 4A), b_2: (1B, 2B, 3E, 4A), b_3: (1B, 2C, 3B, 4A), b_4: (1C, 2C, 3B, 4B), where the codes in brackets refer to the questionnaire answer strategies reported in the Appendix. We have already pointed out that the array describing the cluster centroid describes to the answers most frequently given by the students in the cluster, and in this sense we can identify at what frequency each answering strategy is shared by the cluster students.

In particular, cluster Cl_4 is mainly composed of students that use higher level answering strategies to deal with the concepts in the questionnaire. In fact, these students recognize that a model *is a mental representation of a real object or phenomenon,which takes into account the characteristics that are significant for the modeler* (1C). They also think that models*are creations of human thought and their creation comes from continuous interaction with the "real" external world and from its simplification* (2C) and that a model*must highlight the variables that are relevant for the description and/or explanation of the phenomenon analyzed (or the object studied) and their relationships* (3B). *The modeling process is seen as a construction where the model can still contain errors or uncertainty connected with the possibility (or ability) to carefully reproduce the characteristicswe are interested in* (4B). It is worth noting that only 19% of the students belong to cluster Cl_4 and show an informed view of physics models. Such low percentages are also found in the literature (Grosslight et al., 1991; Treagust et al., 2002), although quantitative comparisons cannot be performed, given the differences in the analyzed samples.

Students in cluster Cl_2 show the weakest understanding of the model concept. They refer to a model as *a simple phenomenon or the exemplification of aphenomenon through an experiment or a reduced scale reproduction of an object*(1B), and believe that *models are simple creations of human thought like mathematical formulas, or physics laws and/or they are what we call theories or scientific method* (2B), and give answers regarding the main characteristics of a model that are confused and unclear (3E). For these students *every natural phenomenon can be simplified in order to be referred to a given model* (4A).

Cl_2 students can be reported to the level II modelers based on the classification scheme developed by Grosslight et al. (1991). Level II modelers see models as representations of real-world objects or events and not as representations of ideas about real-world objects or events. They also see the use of different models as that of capturing different spatio-temporal views of the object rather than different theoretical views. Similar results have been obtained in other studies, as for example paper Treagust et al. (2002), that found a significant group of students with a narrow and naïve understanding of the concept of model as an exact replica: the scale replica, a precise representation, which has accuracy and detail; and the imprecise representation, which doesn't have the accuracy or detail, and may be nothing like the object, but can provide insight into why and how something works the way it does. Some studies involving teacher conception of scientific models (Justi& Van Driel, 2005; Danusso et al.,

2010) report conceptions related to such realistic view, mainly where teachers focus on the role of models as examples of objects/processes or their simplifications. To sum up, we can say that the students in cluster Cl_4 seem to share many conceptions connected with an epistemological constructivist view (Treagust et al., 2002). Students in cluster Cl_2, on the other hand, often held beliefs that correspond with a "naïve realist" epistemology, i. e. they usually considered models to be exact copies of reality, albeit on a different scale, or simplified representations (Treagust et al., 2002).

Students in clusters Cl_1 and Cl_3 do not show a full coherence in their answers, although in different ways. Cl_3 students seem to share with Cl_2 students the ideas concerning the definition of physics models and the modeling process, but they also share their beliefs about the function as well as the characteristics of physics models with the students from cluster Cl_4. In fact, they state that *physics defines models as a simple phenomenon or the exemplification of a phenomenon through an experiment or a reduced scale reproduction of an object* (1B). However, they also say that they *are creations of human thought and their creation comes from continuous interaction with the "real" external world and from its simplification* (2C). Furthermore, they seem to share the idea that in a modeling process it is important *to highlight the variables that are relevant for the description and/or explanation of the phenomenon being analyzed (or the subject being studied) and their relationships* (3B) and *that every natural phenomenon can be simplified in order to be referred to a given model* (4A). Such conception of physics model can be reported to literature findings (Fazio et al., 2013; Hrepic et al., 2005) that analyze students' reasoning in different fields and define some kinds of reasoning as ''hybrid models'' (Ding & Beichner, 2009) or ''synthetic models'' (Justi & Gilbert, 2002), by referring to composite mental models that unify different features of initial spontaneous models and scientifically accepted models. Research reveals (Bao & Redish, 2006; Hrepic et al., 2005) that a student can use different mental models in response to a set of situations or problems considered equivalent by an expert. In particular, Bao and Redish (2006) developed a way to deal with these composite mental models and define students' model states that can change with specific contextual features in different equivalent questions. Our data point out that such inconsistency is deployed in the elicitation of model constituents as well as of functions and characteristic of the modeling process.

Students in cluster Cl_1 share the idea that a model is a *mental representation aimed at describing a real object or a phenomenon, which takes into account the characteristics that are significant for the modeler* (1C). However, they also think that *models are simple creations of human thought, like mathematical formulas or physics laws, and/or they are what we call theories or scientific method* (2B). These ideas are not completely consistent with the characteristics assigned to the model or with the students' ideas about the modeling process. In fact they declare that a model *must contain all the rules or all the laws for a simplified description of reality and/or it must account for all the features of reality* (3A) and *that every natural phenomenon can be simplified in order to be referred to a given model* (4A). Their focus on the process of *"simplification"* is also made explicit in the examples they report in order the explain their sentences. For example, for many of such students "the motion without friction is a model as well as the perfect gas (not the motion with friction or real gases".

On the other hand, it must be taken into account that the value of the reliability, r_k^{norm}, of the C_1 centroid is the lowest, showing that array b_1 is not very significant in representing the answering strategies of thecluster students. Also, looking in detail at b_1 array, the answering strategies are not easily understandable from the point of view of consistency and although they represent the answers most commonly given by Cl_1 students, these do not have very high frequencies. For example, no more than 38% is assigned to category 1C. Other answers were also given by a large number of students; for example answering strategy 1B (*A physics model is a simple phenomenon or the exemplification of a phenomenon through an* *experiment or a reduced scale reproduction of an object)* was selected by 30% of Cl_1 students. In our opinion, this may show that a substructure is present in cluster Cl_1, and this should be analyzed through different analysis methods, like, for example Hierarchical Cluster Analysis (Everit et al., 2011), that can point out a higher number of clusters and help to make sense of them.

In conclusion, in this paper, we discussed the problem of quantifying qualitative data in order to analyze how to identify groups with common behavior, ideas, beliefs and conceptual understanding in a sample of students. We presented a method of cluster analysis and analyzed definitions, variables and algorithms in detail, in order to understand the possibilities offered by such a method and its limits. We gave an example of their application in order to demonstrate the necessary approximations and the different ways of interpreting results. The example is an analysis of the answers to a questionnaire given to a sample of university students. It is worth remembering that data that are quantitatively analyzed are the results of a categorization of raw data (the individual student answers) and this reduction of the initial data can be subject to errors, which obviously influences the final evaluation and the inference about the reasoning strategies supporting students' answers. Such errors can only be reduced (through a clear process of coding and subsequent categorization) and not eliminated, and this must be taken into account when we try to infer typical students' reasoning strategies.

Looking at the meaning of the concept of a physics model as understood by the students in our sample, our results are consistent with those described in the literature, which illustrate a continuum of ideas/beliefs ranging from naive conceptions to constructivist ones (Grosslight et al., 1991; Van Driel & Verloop, 1999, Treagust et al., 2002; Pluta et al., 2011) . Our analysis gives details of student conceptions about the function of a physics model and its properties, by identifying features of intermediate conceptions as well as groups of students sharing such conceptions, in a continuum of this type. Furthermore, the results of this study provide important hints and insights for teaching methods that may improve students' model-based reasoning, and provide teachers with information about their students' level of understanding, with which they can make instructional decisions.

REFERENCES

Bao, L. & Redish, E. (2006). Model analysis: Representing and assessing the dynamics of student learning, *Phys. Rev. ST Phys. Educ. Res.* **2**, 010103.

Borg, I. & Groenen, P. (1997). *Modern multidimensional scaling*. New York: Springer Verlag.

Chi, M. (1997). Quantifying Qualitative Analyses of Verbal Data: A Practical Guide, *The Journal of the Learning Sciences* **6(**3), 271-315.

Danusso, L., Testa, I. & Vicentini, M. (2010). Improving Prospective Teachers' Knowledge about Scientific Models and Modelling: Design and evaluation of a teacher education intervention, *International Journal of Science Education* **32**(7), 871-905.

Ding, L. & Beichner, R. (2009). Approaches to data analysis of multiple-choice questions, *Phys. Rev. ST Phys. Educ. Res.* **5**, 020103.

Everitt, B., Landau, S., Leese, M. and Stahl, D. (2011). *Cluster Analysis*. Chichester, UK: John Wiley & Sons, Ltd.

Fazio, C., Di Paola, B. & Guastella, I. (2012). Prospective elementary teachers' perceptions of the processes of modeling: A case study, *Phys. Rev. ST Phys. Educ. Res.* **8**, 010110.

Fazio, C., Battaglia, O. & Di Paola, B. (2013). Investigating the quality of mental models deployed by undergraduate engineering students in creating explanations: the case of thermally activated phenomena, *Phys. Rev. ST Phys. Educ. Res.* **9**, 020101.

Gower, J. (1966). Some Distance Properties of Latent Root and Vector Methods Used in Multivariate Analysis, *Biometrika Trust* **53(**3/4), 325-338.

Green, E. (2001). Can Qualitative Research Produce Reliable Quantitative Findings? *Field Methods* **13(**1), 3–19.

Grosslight, L., Unger, C., Jay, E.& Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts, *Journal of Research in Science Teaching* **28**, 799–822.

Hammer, D. & Berland, L. (2014). Confusing Claims for Data: A critique of Common Practices for Presenting Qualitative Research on Learning, *Journal of the Learning Sciences* **23,** 37-46**.**

Hrepic, Z., Zollman, D. & Rebello, S. (2005). Eliciting and Representing Hybrid Mental Models. *Annual International Conference of the National Association for Research in Science Teaching, April 4-7, Dallas, TX*. http://ldsp01.columbusstate.edu:8080/xmlui/handle/11075/723

Justi, R. & Gilbert, J. (2002). Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science. *International Journal of Science Education* **24**(12), 1273–1292.

Justi, R. & Van Driel, J. (2005). The development of science teachers' knowledge on modelsand modelling: Promoting, characterizing, and understanding the process. *International Journal of Science Education* **27**(5), 549–573.

MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. In: L. Le Cam, J. Neyman (Eds.): *Proc. 5th BerkelySymp. Math. Statist. Probab. 1965/66*, (vol. I, pp. 281-297). Berkely: Univ. of California Press.

Pluta, W., Clark, A.,Chinn, A., Ravit Golan Duncan, R. (2011). Learners' Epistemic Criteria for Good Scientific Models, *Journal of Research in Science Teaching* **48**, 486–511

Rouseeuw, P. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis, *Journal of Computational and Applied Mathematics* **20,** 53-65**.**

Sokal, R. & Sneath, P. (1963). *Principles of Numerical Taxonomy*. San Francisco and London: W. H. Freeman & Co.,)

Stewart, J., Miller, M., Audo, C. & Stewart, G. (2012). Using cluster analysis to identify patterns in students' responses to contextually different conceptual problems, *Phys. Rev. ST Phys. Educ. Res* .**8**, 020112

Struyf, A., Hubert, M. & Rousseeuw, P. (1997). Clustering in an Object-Oriented Environment. *Journal of Statistical Software* **1**(4), 1-30.

Treagust, D., Chittleborough G. & Mamiala, T. (2002). Students' understanding of the role of scientific models in learning science, *International Journal of Science Education* **24**(4),357-368.

Tryon, R. (1939). *Cluster Analysis: Correlation Profile and Orthometric (factor) Analysis for the Isolation of Unities in Mind and Personality*.Ann Arbor: Edwards Brothers.

Tumminello, M., Micciché, S., Dominguez, L., Lamura, G., Melchiorre, M., Barbagallo, M. & Mantegna, R. (2011). Happy Aged People Are All Alike, While Every Unhappy Aged Person is Unhappy in Its Own, *PLoS ONE* **6**(9): e23377.

Wittmann, M. & Scherr, R. (2002). Student epistemological mode constraining researcher access to student thinking: An example from an interview on charge flow. In K. Cummings, J. Marx, & S. Franklin (Eds), *Physics Education Research Conference Proceedings 2002* (p. 43–46). Boise (USA): PERC Publishing.

Van Driel, J. & Verloop, N. (1999). Teachers' knowledge of models and modelling in science, *International Journal of Science Education* **21(**11), 1141-1153.

APPENDIX. QUESTIONNAIRE AND ANSWERING STRATEGIES

Q1. The term "model" is very common in scientific disciplines, but what actually is the meaning of "model" in physics?

1A) A set of variables or rules or laws or experiments and observations that simplify reality and represent it in a reduced scale.
1B) A simple phenomenon or the exemplification of a phenomenon through an experiment or a reduced scale reproduction of an object.
1C) A mental representation aimed at describing a real object or a phenomenon, which takes into account the characteristics significant for the modeler.
1D) A simplified representation describing a phenomenon aimed at the understanding of its mechanisms of functioning (or at explaining it or at making prediction).
1E) No answer or not understandable answer

Q2. Are the models creations of human thought or do they already exist in nature?

2A) Models really exist and are simple, real life situations or simple experiments and humans try to understand them, sometimes only imperfectly.
2B) Models are simple creations of human thought like mathematical formulas, or physics laws and/or they are what we call theories or scientific method.
2C) Models are creations of human thought and their creation comes from continuous interaction with the ‘‘real’’ external world and from its simplification.
2D) Models are creations of human thought aimed at explaining natural phenomena and making predictions.
2E) No answer or not understandable answer

Q3. What are the main characteristics of a physical model?

3A) It must contain all the rules or all the laws for a simplified description of reality and/or it must account for all the features of reality.
3B) It must highlight the variables that are relevant for the description and/or explanation of the phenomenon analyzed (or the object studied) and their relationships.
3C) Their characteristics can classify models as descriptive or explicative or interpretative.
3D) Their main characteristics are simplicity and/or uniqueness and/or comprehensibility.
3E) No answer or not understandable answer.

Q4. Is it possible to build a model for each natural phenomenon?

4A) Yes, every natural phenomenon can be simplified in order to be referred to a given model.
4B) Yes, but the model can still contain errors or uncertainty connected with the possibility (or ability) of carefully reproducing the characteristics we are interested.
4C) No. There are phenomena that cannot be described or explained with a model and/or that cannot be defined in terms of precise physical quantities.
4D) No. There are phenomena that have not been still explained and these, perhaps, will be in the future.
4E) No answer or answer not understandable

THE ROLE OF ICT TO CHANGE MISCONCEPTIONS OF SOME ASTRONOMY CONCEPTS IN CHILDREN OF PRIMARY SCHOOL

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Abstract: This study was designed to investigate whether the use of Information and Communication Technologies (ICT) would be fruitful to change several misconceptions of students about astronomy (the solar system, stars, etc.). It was developed with a group of 23 children, aged between eight and nine years old, who attended the 3rd grade of primary education in a school in Lisbon, Portugal. This research can be classified as an action-research project based on a quasi-experimental study in the context of teaching practice leading to a master´s degree qualifying the students to be teachers in the first six years of schooling. The research was developed in several stages, being initiated with the application of a questionnaire to identify misconceptions about astronomy. The result of this application confirmed that these misconceptions were similar to those already identified by other studies with children of the same age. Subsequently, ICT were used to design activities to promote conceptual change in order to provoke cognitive conflicts in the children about their own ideas when compared with scientific ones. After this intervention, the same questionnaire was applied in two different moments in order to evaluate possible changes. The first application was at the end of the school year, right after the above mentioned treatment; the second application took place at the end of September, in the following school year, after the summer school holidays. In both applications, a marked decrease of the misconceptions held by the children was revealed, which indicates that the use of ICT can be a relevant tool to promote a persistent conceptual change.

Keywords: Primary School; Misconceptions; Astronomy concepts

INTRODUCTION

Scientific concepts are ideas that can help us to understand how the world functions. However, each of us constructs, since childhood, their own interpretations of a large variety of phenomena based on daily experience. These interpretations are very often scientifically incorrect and are commonly called misconceptions (Martin, Sexton, & Gerlovich, 2002; Anderson, Fisher & Norman, 2002; Kose, 2008). When at school, these misconceptions for scientific phenomena interfere in the learning process of pupils. As Allen (2014) mentions, pupils at school do not absorb scientific ideas in a passive way but try automatically to connect their own knowledge with the new material that teachers approach during lessons. And even when facing new concepts for the first time in a formal learning context, these conceptions may also be constructed.

It is a naïf idea to think that these misconceptions can be easily changed, only by the correct explanation of scientific phenomena. On the contrary, they are resistant to change and have an impact in school learning (Carmichael et al., 1990; Santos, 1991). For Santos (1991), a proof of this resistance stems from the fact that these ideas return, even after an apparently rigorous and structured approach of the scientific contents in formal education and persist along adulthood. And Allan (2014), based on several studies, states that, since misconceptions are useful, consistent and good enough to explain everyday phenomena, their owners don´t feel the necessity to change their own ideas. Allan gives an example: The misconception that the Earth is closer to the sun during July (in summertime) makes apparently more sense than the real situation that our planet is in the furthest position from the sun during this time of the year. Rowell, Dawson & Lyndon (1990) also quote that pupils frequently conceive two different worlds, using the correct concept in the formal context but revealing the corresponding misconception in their daily life. The main problem is that the correct concept is frequently no longer necessary after leaving school.

In fact, to change pupils’ misconceptions effectively is a very hard work and several steps are needed without a guarantee of success extended to all the pupils.

To start with, the identification of pupils’ misconceptions can help teachers to better design learning activities in order to promote cognitive conflicts leading to their eradication. In fact, this initial process can prove essential to facilitate a meaningful learning of a scientific content. The strategies for this identification can include, for instance, addressing pupils directly about their own ideas, asking them to draw a concept, using concept maps, using scientific apparatus or promoting a role playing activity. The selection of these strategies depends a lot on pupils’ age and on the nature of the concepts we want to identify, but the principle is quite simple: a learning process not focused on the teacher allows a greater exposure of pupils' thinking and an easier identification of the misconceptions that they have about several scientific ideas. But for this identification, teachers can also appeal to the results of a multitude of studies with students of different ages which have sought to identify misconceptions related to a variety of scientific issues.

It is true that learning is an idiosyncratic process and that a multiplicity of misconceptions can be generated. But, in practice, for each scientific concept, a few misconceptions are normally detected in different samples with different cultural contexts, even knowing that some ideas are in fact specific of a certain cultural reality (Allen, 2014).

To promote conceptual change Posner, Strike, Hewson & Gertzog (1982) claim the following conditions as essential: i) dissatisfaction – if the concept owned by pupils does not solve a current problem; ii) intelligibility – if the correct concept can be understood; iii) plausibility – if it works to solve present discrepancies, iv) applicability - if its applicability can solve future problems. To achieve these conditions it is also important to design powerful strategies and activities. It is in this context that the use of New Information and Communication Technologies (ICT) was considered as a potential tool for this purpose.

The main aim of the present research

The present research aimed at the following objectives:

● To verify the incidence of certain misconceptions that literature highlights as frequent in children of the 1st cycle of primary education related with the solar system, stars, etc.;

● To verify if activities based on Information and Communication Technologies (ICT) can help to change these misconceptions

According to Miranda (2007), ICT are a combination of computer technology with telecommunications that have on the Internet their form of greater expression. Nowadays, ICT are widespread in society, promoting important changes in our forms of communicating, as well as the way we access knowledge. Most children are acquainted with ICT and School feels that it should take advantage of this knowledge and of the skills associated with their handling, which are often developed at home and in other non-formal contexts.

Indeed, it is sometimes difficult to be aware of how ICT are already part of our daily lives and of how their integration has been taking place increasingly in the Portuguese education system. Even so, in Portugal, this integration has been uneven in the different cycles of schooling and slower in primary school (1st cycle). For this fact several factors can be identified, as the smaller investment of the political power in the first years of schooling, with reflection in the lack of equipment essential for the implementation of ICT activities, or the lack of teacher training related with their use.

All this divestment is contrary to the educational potential of ICT claimed by several authors. For instance, to Kozma (2005), the use of ICT in education has several advantages, like the following: (i) to facilitate access to education and knowledge; (ii) to focus on learning, increasing the digital literacy of citizens; (iii) to enhance integrated learning in the different areas of the curriculum (iv) to promote knowledge creation, technological innovation and the sharing of knowledge; (v) and it can also help to improve meaningful learning which can contribute to the desired conceptual change. Harlen & Qualter (2008) also highlight several benefits to teachers and learners by using ICT: teachers can have visual aids, explore ideas more effectively by using different types of software; pupils can interact and have an active role by discussing information and also presenting it in a more innovative way.

However, Solomon (1983) pointed out, more than three decades ago, that children's exposure to media can also promote misconceptions. Hence, the use of ICT does not seem to exempt the active role of the teacher, especially as a tutor of the learning process, also selecting the best strategies that lead to their use (Santrock, 2009).

METHOD

This study is an action-research project based on a quasi-experimental model. It was developed in a primary school of Lisbon between April and September of 2014 in the context of teaching practice, a curricular unit that is included in a master´s course qualifying students to be teachers in the first 6 years of schooling. Teaching practice occurs always in real contexts during a month and a half and in-service teachers yield their classes for this purpose. During this time, students teach all the areas of the curriculum, which include, beyond Science, Mother Tongue (Portuguese), History, Geography, Math and Artistic Expressions. At the same time, a research issue related with their practice should be designed and implemented.

At the beginning of teaching practice, each student must define, after a period of observation, their own intervention aims. In the present case, the teaching practice occurred in a 3rd grade class with 23 students, 17 female and six male aged between eight and nine years old. The children were from middle class, and their parents have either secondary or higher education. One of the aims was to promote the understanding of scientific concepts, deconstructing misconceptions in a persistent way. With this purpose the following objectives were defined:

-to identify misconceptions related with astronomy concepts in the class where teaching practice occurred;

-to use ICT activities, especially PowerPoint presentations, short videos from YouTube and interactive games, to discuss the above mentioned misconceptions, promoting cognitive conflicts in the pupils;

-to promote class discussions about the misconceptions, comparing right and wrong ideas;

-to verify changes in the misconceptions, after the intervention period.

The steps and the main aims of the study are presented in Table 1.

Table 1. The several steps of the present study.

List of the different steps
1st step – Literature revision Main aim: To identify the misconceptions related with the research theme in other studies
2nd step – Building of the questionnaire and its validation Main aim: To build a questionnaire based on several misconceptions related with the solar system, stars, etc. to verify their presence in the pupils
3rd step - First administration of the questionnaire (End of April) Main aim: To administrate the questionnaire before the period of teaching practice related with the theme
4th step - Analysis of children´s responses Main aim: To conform the presence of the same misconceptions revealed by literature
5th step – Design of the ICT activities and their implementation Main aim: To design ICT activities especially through the deconstruction of the misconceptions that are most common
6th step - Second administration of the questionnaire and analysis of children´s responses (End of May) Main aim: To verify possible changes after the teaching practice period
7th step - Third administration at the beginning of the next school year (End of September) Main aim: To verify the persistence of those changes

Several misconceptions about the solar system, stars, etc. in children of a similar age of the sample of the present study were identified in studies from Schoon (1989), Hapkiewicz (1992), Langhi & Nardi (2011) and Teixeira (2011), for instance. Based on these results, a questionnaire with open and closed questions was built. In this questionnaire, it was impossible to include all the misconceptions related with this issue. Therefore, the selection was related with the concepts present in the 1st Cycle curriculum, which are: the shape of the earth, the phases of the moon, the differences between stars and planets and the main characteristics of the solar system.

Before its administration, the questionnaire was validated by two experts in didactics and piloted with eight children of the same age and social characteristics. The questionnaire included the questions present in Table 2.

The questionnaire was applied (pre-test) to the sample at the end of April of 2014. The verification of the incidence of certain misconceptions was essential for a better selection of the didactic resources related with ICT to promote conceptual change. The resources were the ones already mentioned. The videos were always presented twice and a discussion was promoted between the two presentations of the same video. This discussion intended to focalize pupils in the understanding of scientific concepts with a higher incidence of misconceptions. After four weeks, at the end of May, the questionnaire was administered again (post-test1) to verify possible first changes in these misconceptions. Finally, at the end of September, in the following school year, the same questionnaire was administered again to verify the consistence of the conceptual change (post –test2).

Each questionnaire was quoted as follows: the value "1", for each right question, in which the student did not reveal a misconception and "0" in the opposite situation. In the multiple choice items, a reason was demanded and these answers were categorized by content analysis. An answer was only considered correct when the justification matched the chosen option.

Table 2. The questions included in the questionnaire.

Questions	Their nature
1.1.The Sun is … (a planet, a comet, a satellite)	Multiple choice
1.2. The celestial bodies that own light are… (the planets, the stars, the comets, the asteroids)	Multiple choice
1.3. The phase of the moon that we observe is… (always the same, depends on the earth´s place)	Multiple choice
2.1. The solar system ends on the last planet. (True, False – Justify)	Multiple Choice Justification: Open question
2.2. The Earth is bigger than the Sun. (True, False – Justify)	Multiple Choice Justification: Open question
2.3. All the planets are rocky. (True, False – Justify)	Multiple Choice Justification: Open question
2.4. The stars have tips. (True, False – Justify)	Multiple Choice Justification: Open question
3. Given the position of the Sun and the planets, which of the schemes, A (geocentric model) or B (heliocentric model), represents the solar system?	Multiple Choice Justification: Open question

The global quotation of the questionnaires was compared for the first and second administrations and for the first and the third ones, applying the Wilcoxon signed-rank non-parametric test, since the pattern of responses not always followed a normal distribution. The level of significance adopted was $p<0.05$.

RESULTS

Table 3 presents the questions included in the questionnaire as well as the incidence of the wrong ideas (misconceptions) in the three moments of its administration.

In the pre-test, several children revealed the same misconceptions present in other studies. With a high incidence, 78% of the children thought that a moon phase varies with the place where we are on earth and 57% thought that stars have tips. In relation to the Earth size when compared with the Sun and the physic nature of the planets of the solar system, the percentage of incorrect answers was also high, now aided by the discrepancy between the option in a multiple choice item and its justification. Table 4 shows some of the justifications expressed by the pupils.

Table 3. Percentage results from the questionnaires (pre-test, post-test1 and post-test2). The sample consists of 23 children. The scientific conception is in bold.

Questions	Relative frequencies		
	Pre-test	Pos-test1	Pos-test2
1.1.The Sun is …			
a planet.	9%	0%	0%
a comet	4%	0%	0%
a satellite.	4%	0%	0%
a star.	83%	100%	100%
1.2. The celestial bodies that own light are…			
the planets.	35%	0%	0%
the stars.	30%	100%	96%
the comets.	22%	0%	4%
the asteroides.	13%	0%	0%
1.3. The phase of the moon that we observe…			
is different from country to country .	35%	0%	4%
is different from continent to continent.	17%	0%	4%
is different in each hemisphere.	26%	0%	13%
is the same in the whole planet.	22%	100%	78%
2.1. The solar system ends on the last planet.			
True	26%	0%	9%
False	48%	100%	91%
Not scored. The justification does not match the chosen option	26%	0%	0%
2.2. The Earth is bigger than the Sun.			
True	35%	8%	4%
False	48%	88%	96%
Not scored. The justification does not match the chosen option	17%	4%	0%
2.3. All the planets are rocky.			
True	35%	0%	0%
False	43%	91%	96%
Not scored. The justification does not match the chosen option	22%	9%	4%
2.4. The stars have tips.			
True	57%	0%	0%
False	30%	100%	100%
Not scored. The justification does not match the chosen option	13%	0%	0%
3. Given the position of the Sun and the planets, which of the schemes, A or B, represents the solar system?			
Scheme A (geocentric model)	13%	0%	0%
Scheme B (heliocentric model)	87%	100%	100%

Table 4. Some of the misconceptions revealed by the children. Some of them are only reasons that can not exactly be considered misconceptions.

Questions	Some justifications
2.1. The solar system ends on the last planet.	→ The solar system begins in the first planet and ends in the last.
It´s true because…	→ I learnt it in a movie.
	→ They explained it to me like that.
2.2. The Earth is bigger than the Sun.	→ The sun is only a ball of fire.
	→ In fact they have the same size.
It´s true because…	→ The Earth is bigger.
	→ The Sun is smaller.
	→ Many people think that the sun is bigger. But from the Earth, we can see that the Sun is smaller
2.3. All planets are rocky.	→ Only those that are hit by comets are rocky..
It´s true because…	→ All planets have rocks.
	→ The planets are strong so they have rocks.
	→ The planets could not be composed otherwise.
2.4. The stars have tips.	→ I can see that they have tips.
	→ When I draw a star it has tips.
It´s true because…	→ The stars are pointy
3. Given the position of the Sun and the planets, which of the schemes, A or B, represents the solar system? Scheme A (geocentric) because…	→ It makes sense like that. → In this scheme the planets are in their right positions.

The justifications for the several items were somehow inconclusive. Children tend to justify their ideas without elaborating much, only saying that they learnt it like that or just because it makes sense like that. Even so, a few justifications are quite interesting and we highlight the following: “the earth is bigger than the sun because de sun is only a ball of fire”; “all planets are rocky because they are strong so they have rocks”; “The planets could not be composed otherwise” or “the stars have tips because when I draw one it has tips”.

In the second moment (pos-test1), after the already mentioned treatment using ICT activities, there was a clear reduction of the expressed misconceptions. Even so, still 12% of the children continue to argue that the Earth is bigger than the Sun, and 9% claim that all planets are rocky. This decrease revealed to be consistent because in the results of the 3rd administration the percentage of children with misconceptions was also very small. Nevertheless, the percentage of children considering that the phase of the moon depends on our location on the Earth, as well as those who think that the terminus of the solar system is in the planet more distant from the Sun increased a little. But, at the same time, there was also a small decrease in the number of children stating that the Earth is bigger than the Sun and that all the planets are rocky.

The application of the Wilcoxon signed-rank test showed that the score differences between the first administration and the second, as well as between the first and the third were both statistically significant, respectively $z = -3{,}955$; $p < 0.001$ and $z = -4{,}163$; $p < 0.001$.

CONCLUSIONS AND IMPLICATIONS

This study helped to confirm that some of the misconceptions about the solar system, stars, etc., identified in previous studies, were also present in the children inquired. The complexity of these topics is one of reasons why these misconceptions are not easy to change. Consequently, Kavanagh, Agan & Sneider (2005), based on several studies, stated that a topic like the phases of the moon, for instance, should be addressed at the fifth or sixth grade level, and not below. But it seems that curriculum developers sometimes tend to ignore some of the results of educational research.

The good news are that the use of ICT activities, especially with animations and short films, but always accompanied by a systematic opposition of the aspects observed with the wrong ideas of the children, made it possible to deconstruct the majority of the misconceptions expressed by them, considering that they were at the third level of schooling and have to learn a complex issue. We also think that the already described active role of the teacher was also essential for the success of the intervention.

This study was not exempt of limitations. For instance, it was impossible to compare the results of the pupils of the sample with those from other classes submitted to a different research design or simply to a more traditional approach in which teachers tend to ignore the children´s misconceptions and don´t use ICT activities. After all, the success of the intervention was in part a surprise, since the time to explore science issues was scarce and during the teaching practice period all the curriculum areas were taught.

Independently of the good results, this study also allows to highlight the possibility of every teacher to include a research dimension in the course of their own practice, thus contributing to change at least some of the misconceptions expressed by children about different scientific topics.

REFERENCES

Allen, M. (2014). Misconceptions in Primary Science. Maidenhead: Open University Press.

Anderson, D. L., Fisher, K. M. & Norman, G. J. (2002). Development and evaluation of conceptual inventory of Natural Selection. *Journal of Research in Science Teaching 39*, 952-978.

Carmichael, P., Driver, R., Holding, B., Phillips, I., Twigger, D., & Watts, M. (1990). *Research on students' conceptions in science: A bibliography*. Centre for Studies in Science and Mathematics Education, University of Leeds, United Kingdom.

Hapkiewicz, A. (1992). Finding a List of Science Misconceptions. *The Michigan Science Teachers Association Journal, 38*, 11-14.

Harlen, W. & Qualter, A. (2008). *The Teaching of Science in Primary Schools* (4^{th} Edition). New York: David Fulton Publishers.

Kavanagh, C., Agan, L. & Sneider, C. (2005). Learning About Phases of the Moon and Eclipses: A Guide for Teachers and Curriculum Developers. *Astronomy Education Review 1* (4), 19-52.

Kose, S. (2008). Diagnosing Student Misconceptions: Using Drawings as a Research Method. *World Applied Sciences Journal 3* (2), 283-293.

Kozma, R. (2005). National policies that connect ICT-based education reform to economic and social development. *Human Technology, 1*(2), 117-156.

Langhi, R. & Nardi, R. (2011). Um estudo exploratório para a inserção da astronomia na formação de professores dos anos iniciais do ensino fundamental. *IX Encontro Nacional de Pesquisa em Ensino de Física*, 1-13.

Martin, R., Sexton, C. and Gerlovich, J. (2002) *Teaching Science for all Children: Methods for Constructing Understanding*. Boston: Allyn and Bacon.

Miranda, G. (2007). Limites e possibilidades dasTIC na educação. *Revista de Ciências da Educação 3*, 41-50.

Posner, J., Strike, K. Hewson, P. & Gertzog, W. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education*, *66*, 211-227.

Rowell. A., Dawson, C. & Lyndon, H. (1990). Changing misconceptions: a challenge to science educators. *International journal of Science Education 12*(2), 167-75.

Santos, M. (1998). *Mudança Conceptual na Sala de Aula – um desafio pedagógico epistemologicamente fundamentado*. Lisboa: Livros Horizonte.

Santrock, J. (2009). *Psicologia Educacional.* Lisboa: McGraw-Hill.

Schoon, K. (1989). Misconceptions in the earth Sciences: A cross-age study. Paper presented at the annual meeting of the national Associations for Research in Science Teaching, CA, ERIC.

Solomon, J. (1983). Learning about energy: how pupils think in two domains. European *Journal of Science Education*, 5 (1), 56-69.

Teixeira, A. (2011). *Concepções alternativas em ciência: um instrumento de diagnóstico.* Available at http://run.unl.pt/handle/10362/7816

STUDENTS' MENTAL MODELS ON ACIDS AND BASES VIA AN ALTERNATIVE ASSESSMENT

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Abstract: Students encounter many real life events from an early age and they relate to what they already know and construct coherent understanding of these events. During in chemistry learning process, students often experience difficulties and lack conceptual understanding of basic concepts even though their effort. In the current study, acids and bases concepts were investigated, which is one of the fundamental topics in chemistry and easily influenced by daily language and experiences. The participants were 40 eleventh grade high school students; and their initial ideas about the acidity and basicity of materials, substances or events, and their understanding of acids and bases concepts to address their nature of mental models of acids and bases were investigated via an alternative assessment tool. In order to assess students' ideas on acids and bases a reading log, one of alternative assessment techniques, was used, which included daily life events that students might find interesting to learn. The most significant finding was that none of the students or groups used any scientific model in determining the acidity or basicity of the substances. Their decisions and explanations in determining the substances' acidity or basicity was quite in basic level, none of them not even consider any scientific exploration when having difficulties in the determination process. Therefore, student-centered instructions with inquiries, hands- and minds-on activities with more laboratory usage, and more frequently giving real-life examples related to topics might increase students' scientific models and meaningful understanding of the concepts. In addition, teachers, curriculum developers, and textbook writers should clearly emphasize on the nature of science to help students understand and interpret their surroundings.

Keywords: Mental Models, Chemistry, High school level, Alternative Assessment

INTRODUCTION

Today, every citizen is expected to be a scientifically literate person by means of being able to understand real life events, having the joy of knowledge about the natural world, applying scientific processes in personal life, asking and suggesting reasonable solutions for questions, make decisions, be good at social communication, and able to use technology.

Chemistry is such a branch that any event in real life may be explained with the help of chemistry, which can also encourage student curiosity and make sense why they learn about chemistry. Students encounter many real life events from an early age and they relate to what they already know and construct coherent understanding of these events. During in chemistry learning process, students often experience difficulties and lack conceptual understanding of basic concepts (Ben-Zvi, Eylon, & Silberstein, 1986; Krajcik, 1991; Nakhleh, 1992; Osborne & Cosgrove, 1983). Students usually tend to learn factual knowledge presented and tries to grasp the knowledge that they just need for exams, without making any meaningful connections to what they already know or constructing an understanding of the underlying concepts, they only hold their own coherent understanding based on their prior knowledge and experience (Nakhleh, 1992; Osborne & Wittrock, 1983). In the case of Turkish high school students, students are mostly focused on the university entrance examination and performance rather than learning, the important points for them to take high grades in exams, make good memorization to answer the questions rather than inquiring for scientific facts.

In the current study, acids and bases concepts were investigated, which is one of the fundamental topics in chemistry and easily influenced by daily language and experiences. Students' understanding of learning usually is assessed by traditional assessment techniques such as multiple-choice questions, which are often more preferable in science classes since they are easy to apply. Even students are successful in conventional tests, this success does not reveal that the students' understandings of given concepts. A student could get a high score by chance and luck factor; which does not reveal meaning learning. In order to assess students' ideas on acids and bases a reading log, one of alternative assessment techniques, was used, which included daily life events that students might find interesting to learn.

Alternative Conceptions in Acids and Bases

The origin of student difficulties in acids and bases concepts besides the abstractness of the subject (Herron, 1975) could be as well as having alternative conceptions in acids and based concepts (Demerouti et al., 2004; Demircioglu, et al., 2005; Hand, 1989; Hand & Treagust, 1988; Schmidt, 1995; Sheppard, 1997), the lack of understanding of the particulate nature of matter (Nakhleh, 1994; Nakhleh & Kracjik, 1993), the various definitions of acids and bases based on different theories (Schmidt, 1995; Vidyapati & Seetharamappa, 1995; Sheppard, 1997; Furio-Mas et al., 2005; Kousathana, Demerouti, & Tsaparlis, 2005), or experiencing confusing terminology in real world (Schmidt, 1995). Therefore, students should reveal in-depth understanding of some basic concepts such as particulate nature of matter, chemical reactions and chemical equilibrium in order to understand acids and bases concepts.

Hand and Treagust (1988) revealed the students' ideas on acids and bases that they were: "acids eat materials away, acids can burn you, testing for acids can only be done by trying to eat something away, strong acids eat materials away faster than weak acids, reactions of acids with metals and carbonates are examples of acids eating something away, a base is something that makes up an acid, neutralization is the breakdown of an acid or to change from being an acid." Hand and Treagust determined these aforementioned alternative conceptions before the topic of acids and bases and during the topic, then students were enabled to do activities, each of which aimed to remedy one of the aforementioned alternative conceptions. Ross and Munby (1991) conducted a study with high school students on acids and bases via concepts maps and interviews; their findings revealed that students hold alternative conceptions on acids and bases, such as "all acids are strong acids, concentration is the same as strength, a strong acid has a higher pH than a weak acid, and strong acids produce more hydrogen when reacted with a metal than do weak acids." The researchers emphasized that students assumed acids to be more powerful and had difficulties in understanding of bases concepts. Nakhleh (1992) conducted a study with high school students in order to get student models of matter via semi-structured interviews in which students were asked a set of questions about acids, bases, and pH before and after performing a series of titrations. This study disclosed another point of view on acids and bases, expressing that students had poor knowledge of acids and bases since they had lack of understanding of the particulate nature of matter.

Additionally, students had difficulties in transforming verbal definitions to drawings because of confusion in representations of matter as particulate and continuous. Vidyapati and Seetharamappa (1995) interviewed higher secondary school students and compiled a questionnaire regarding acids and bases. The researchers found that students had an alternative conception that acids and bases reactions always resulted in a neutral solution. Additionally, the researchers argued that students were not able to connected acids and bases with real life experiences since they just gave examples of acids and bases from their textbooks. Smith and Metz (1996) conducted a study with graduate and undergraduate chemistry students to evaluate their understanding of acid strength and solution chemistry.

The findings of students' microscopic representations revealed that students had difficulties in representations although they did not have any problems in solving mathematical problems in acids and bases. Students misrepresented ions, bonding and dissociation on acid strength though they successfully defined acid strength verbally.

The literature review reveals that students have some ideas about acids and bases; however, their ideas are not consistent with the scientists and they generally find chemistry abstract, complex and difficult to learn. Students' alternative conceptions about science that may be developed via interactions with parents, peers, teachers or objects in everyday life and are not considered correct from the scientific point of view are often resistant to change.

There is substantial amount of literature on students' alternative conceptions in acids and bases but these studies do not generally focused on the background of these alternative conceptions; addressing the mental models could help determining the source of the alternative conceptions. The study of Coll, France and Taylor (2005) stated that mental models are crucial in the learning process because these mental models provide valuable information about students' conceptual frameworks and reflect their beliefs on concepts. For assessing students' mental models, an alternative assessment tool was developed instead of using a traditional tool since this tool could be more motivating for students to learn about acids and bases they encounter in their everyday life. Therefore, the primary aim of the paper is to state an empirical evidence on students' mental models via alternative assessments.

DESIGN OF THE STUDY

Subjects

The sample of the present study consisted of 40 eleventh grade students (52.5% girls and 47.5% boys). The students participated in the study were about 17 or 18 years old. Students were not much different in terms of the education level of their parents, income, or living standards. Most of the students took additional support for their courses. Students in elementary level learn about acids and bases; therefore, the students had some ideas about acids and bases.

Instruments

Reading logs were used in this study, which were developed by the authors as an alternative assessment tool and was also an introduction activity designed for students to introduce them with some acidic and basic substances they often used in their daily life; and also to make them aware that not all acids or bases are dangerous or hazardous, some of which are directly in our daily life, in our food or surroundings.

There were two version of this reading log (see Figure 1); the purpose of the first version was to get student ideas about what materials, substances or events they thought to be related with acids and bases in their everyday life, and the purpose of the second version was to give the informative knowledge about acidic or basic materials, substances or events related to acids and bases; such as soap is an alkali substance or in the process of baking a cake how the cake rises was explained emphasizing the reaction of acids with carbonates. The students in groups discussed their previous ideas using the second version of the instrument.

Additionally, these reading logs aimed to motivate students to learn about acids and bases concepts. Some basic knowledge (such as what materials in a daily life are acidic or basic), explanations of daily events (such as why statues get deformed), practical knowledge or key points (such as not to use acidic detergents with alkali ones), and open-ended queries (such as how a cake rise) related to acids and bases were given in the instrument to increase their interest to the subject and made them curious about the acids and bases unit.

a. b.

Figure 1. Examples of the screenshots of the reading logs (a. the first version querying student ideas on acids and bases from daily life, b. the second version with details about acidic and basic materials form daily life)

Data analysis

The categorization of the students' mental models was done by one of the researchers and for the reliability of the categorization another experienced educator also did the categorization and the reliability of raters was 96%. The categorization of students' mental models is shown at the Table 1. The substances which were students not sure about their acidity or basicity were determined for the future activities as these substances were going to be used specifically by the students; therefore, the students themselves could make experiments to determine the substance's acidity or basicity.

FINDINGS

The goal of the instrument was to determine students' prior knowledge and their thoughts for substances of being acidic or basic. The students' individual and group ideas about the substances acidity or basicity were both considered in the categorization section (see Table 2). There were some substance which were the students not sure about their acidity or basicity, they were toothpaste, milk, onion, aspirin, and mineral water. The students also mentioned that they realized that they very often came across acidic and basic substances in their everyday life.

Table 1. The categorization of students' mental models

Mental model	Sub-criteria	Definition
Property	Flavor	Students determine the acidity or basicity of the substance based on its flavor, bitter or sour.
	Toxicity	Students determine the acidity or basicity of the substance based on being toxic, eatable or not eatable.
Ingredients	Made of	Students determine the acidity or basicity of the substances based on its consisting matters.
	Contain gas	Students determine the acidity or basicity of the substance based on the solution involves gases.
Character	Surface name	Students determine the acidity or basicity of the substance based on the names of the substances.
Previous knowledge	Being told or heard of	Students determine the acidity or basicity of the substance based on being told by teachers, elders, peers, etc., or heard on TV.

Table 2. The categorization of the students' responses

Mental model	Sub-criteria		Examples (with student quotations)
Property	Flavor	Bitter	Base – Chocolate, soap, onion, aspirin, tea ("When there is no sugar in it, its taste is bitter. Bases have a bitter taste.")
		Sour	Acid – Vinegar, milk, apple, lemon
	Toxic	Eatable	Acid – Aspirin, fruits ("We can eat them, can't be basic"), chocolate ("Something we can eat."), onion, tear drops, salt, baking soda ("My mom makes a cake with it; if we can eat it, it is an acid.")
		Not eatable	Base – Soap, toothpaste, washing detergent
Ingredients	Made of		Acid – Dairy products (Airan ("Since it is made of yogurt"), yogurt ('Since it is made of milk'))
	Contain gas		Acid – Coke, mineral water ("It contains some gases like coke"), tea, coffee, baking soda
Character	Surface name		Acid – Stomachache (stomach acids), acid rain
Previous knowledge	Being told or heard of		Saliva ("Our biology teacher told us, saliva is basic"), stomachache (stomach acids, "I know stomach has an acid from the biology course"), coke ("My mom said it is acidic"), rain (acid rains, "I heard about acid rain"), washing detergents

CONCLUSIONS AND DISCUSSION

In this study, the most significant finding was that none of the students or groups used any scientific model in determining the acidity or basicity of the substances. Their decisions and explanations in determining the substances' acidity or basicity was quite in basic level, none of the students or groups not even consider any scientific exploration when having difficulties in the determination process. This lack of scientific attribution may indicate that the students' mental models were not much developed as expected. If students know about how to seek for knowledge, they will achieve better and enhance meaningful learning. For instance, some students thought that all bases were toxic and harmful for people; for this reason, teachers should give more examples of weak bases and also acids from daily life. In the study of Schnotz and Kurschner (2008), it was stated that the students' mental models were affected by exposure to external representations.

Therefore, students should experience more activities using basic materials from daily life and given more examples related to real world. Activities that could develop students' mental model should be more taken into account into classroom since the studies support the improvement of students' mental models (Coll & Treagust, 2003; Hubber, 2006). Hence, student-centered instructions with inquiries, hands- and minds-on activities with more laboratory usage, and more frequently giving real-life examples related to topics might increase students' scientific models and meaningful understanding of the concepts. Conducting instructional activities enhance the students to explicit their ideas and involving them to learning process, the students become more aware of their own learning, use their learning in daily context, and make interpretations from daily events. Furthermore, students are more motivated to learn scientific concepts when the concepts include familiar situations to them, which also promote their interest in chemistry learning. In addition, teachers, curriculum developers, and textbook writers should clearly emphasize on the nature of science to help students understand and interpret their surroundings. Furthermore, longitudinal studies could provide better insights on how students' mental models develop over time.

REFERENCES

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1986). Is an atom of copper malleable? *Journal of Chemical Education, 63*(1), 64-66.

Coll, R. K., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: Implications from research. *International Journal of Science Education, 27*(2), 183-198. doi: 10.1080/0950069042000276712

Coll, R. K., & Treagust, D. F. (2003). Learners' mental models of metallic bonding: A cross-age study. *Science Education, 87*(5), 685-707. doi: 10.1002/sce.10059

Demerouti, M., Kousathana, M., & Tsaparlis, G. (2004). Acid-base equilibria, Part I. Upper secondary students' misconceptions and difficulties. *The Chemical Educator, 9*, 122-131.

Demircioğlu, G., Ayas, A., & Demircioğlu, H. (2005). Conceptual change achieved through a new teaching program on acids and bases. *Chemistry Education Research and Practice, 6*(1), 36-51.

Furio-Mas, C., Calatayud, M.L., Guisasola, J., & Furio-Gomez, C., (2005). How are the concepts and theories of acid-base reactions presented? Chemistry in textbooks and presented by teachers. *International Journal of Science Education, 27*, 1337-1358.

Hand B., (1989). Student understanding of acids and bases: A two year study. *Research in Science Education, 19*, 133-144.

Hand, B. M. & Treagust, D. F. (1988). Application of a conceptual conflict strategy to enhance student learning of acids and bases. *Research in Science Education, 18*, 53-63.

Herron J. D., (1975). Piaget for chemists. Explaining what 'good' students cannot understand. *Journal of Chemical Education, 52*, 146-150.

Hubber, P. (2006). Year 12 students' mental models of the nature of light. *Research in Science Education, 36*(4), 419-439. doi: 10.1007/s11165-006-9013-x

Kousathana, M., Demerouti, M., & Tsaparlis, G., (2005). Instructional misconceptions in acid base equilibria: An analysis from a history and philosophy of science perspective. *Science and Education, 14*, 173-193.

Krajcik, J. S. (1991). Developing students; understanding of chemical concepts. In S. M. Glynn, R. H. Yeany, & B. K. Brittion, *The Psychology of Learning Science* (pp.117-147) New Jersey: Lawrence Erlbaum Associates, Inc.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education, 69*(3), 191-196. doi: 10.1021/ed069p191

Nakhleh, M. B. (1994). Students' models of matter in the context of acid-base chemistry. *Journal of Chemical Education, 71*(6), 495-499.

Nakhleh, M. B. & Krajcik, J.S. (1993). A protocol analysis of the influence of technology on students actions, verbal commentary, and thought processes during the performance of acid-base titrations. *Journal of Research in Science Teaching, 30*, 1149-1168.

Osborne, R. J., & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching, 20*(9), 825-838.

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education, 67*(4), 489-508.

Ross, B., & Munby, H. (1991). Concept mapping and misconceptions: a study of high school students' understandings of acids and bases. *International Journal of Science Education, 13*, 11-23. doi: 10.1080/0950069910130102

Schmidt, H. (1995). Applying the concept of conjugation to the Bronsted theory of acid-base reactions by senior high school students from Germany. *International Journal of Science Education, 17*, 733-741.

Schnotz, W., & Kürschner, C. (2008). External and internal representations in the acquisition and use of knowledge: Visualization effects on mental model construction. *Instructional Science, 36*(3), 175-190. doi: 10.1007/s11251-007-9029-2

Sheppard, K. (1997). *A qualitative study of high school students' pre and post instructional conceptions in acid-base chemistry*, Ed. D. Thesis, Teachers College, Columbia University, New York.

Smith, K. J., & Metz, P. A. (1996). Evaluating student understanding of solution chemistry through microscopic representations. *Journal of Chemical Education, 73*, 233-235.

Vidyapati, T. J., & Seetharamappa, J. (1995). Higher secondary school students' concepts of acids and bases. *School Science Review, 77*, 82-84.

INTEGRATION OF MACROSCOPIC AND SUBMICROSCOPIC LEVEL FOR UNDERSTANDING FUNDAMENTAL CHEMICAL CONCEPTS USING WEB-BASED LEARNING MATERIAL

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*Abstract:*This study within PhD project is focused on a part of chemistry curriculum in the 8th grade of primary school in Bosnia and Herzegovina and on studying effectiveness of teaching strategy with web-based learning material (WBLM) in resolving students' misconceptions on structure of matter. In pilot phase we specified most common students' misconceptions of selected chemical concepts in the 8th grade of primary school chemistry. We have also gathered students' opinions on WBLM and instruments for data collection, and made some changes after processing results. In the main study, focus is set on further development of the teaching strategy with WBLM, especially designed to connect macroscopic observations with interpretation on the submicro level. The study included following topics of the 8th grade primary school chemistry: structure of matter, states of matter, pure substances and mixtures. Sample in main study includes approx. 210 students aged 13 to 14 years: 50 in control group (CG), 85 in experimental group 1 (EG1) and 75 in experimental group 2 (EG2). In EG1 we have tested the effectiveness of WBLM applied as homework for students after teaching, in EG2 students were learning using WBLM on their chemistry classes at school, while the control group was taught using textbook (without WBLM) and teacher centered approach. The following instruments for data collection were used: knowledge tests, tests of intellectual ability and questionnaires. It is expected for results to reflect the impact of the chosen strategy based on WBLM in which will be outlined the link between macroscopic observations and submicroscopic explanations in understanding selected chemical concepts.

Keywords: Macroscopic observations, Submicroscopic level, Web-based learning material, e-Learning, Structure of matter.

INTRODUCTION

Misconceptions or students' ideas not congruent with the scientifically accepted conceptions (Driver et al., 1985) can lead to a range of learning difficulties. They can be a significant barrier for learning various chemistry topics (Garnett et al., 1995) if the teacher does not try to choose the appropriate teaching strategies to reduce the possibility of their occurrence. Teaching strategies in chemistry should lead towards understanding of chemical concepts in a way to include macroscopic, submicroscopic and symbolic level (Johnstone, 1982; Johnstone, 1993). Scientists describe matter on macroscopic (phenomenological) and on submicroscopic (molecular, atomic, kinetic) level, and students need to learn the relationship between levels (Johnstone, 1993; Stieff et al., 2013), which is crucial for explaining concepts described or observed at macrolevel (Gabel, 1994; Papageorgiou& Johnson, 2005). Therefore models, both mental and physical, are very important in understanding chemistry. A chemist works out a mental model and transfers it to physical models for visualization. Learners, however, observe and compare physical models and develop advanced mental models for relevant issues (Barke et al., 2012).

Complete understanding of chemical concepts is acquired only when all three conceptual levels are interchanging in students' memory (Devetak et al., 2009; Chittleborough, 2014).

According to Piaget's theory of cognitive development, students at age 11 start to develop an abstract way of thinking (Wadsworth, 2004). Learning submicro-macro thinking is abstract and thus can be difficult for students at this age (Gilbert & Treagust, 2009). This implies that those concepts that include processes on submicro level can be too demanding for students if they are taught using teacher-centered teaching.

Web-based learning material (WBLM) is intended to support teaching chemistry within teaching strategy called e-learning. E-learning is defined as an instruction delivered on a digital device such as a computer or a mobile device that is intended to support learning (Clark and Mayer, 2011.).

WBLM contains a variety of media elements: text, audio, still and motion visuals, and it is designed for teaching structure of matter and particulate nature of matter by connecting submicro and macro level of representation. At this stage symbolic level is not introduced.

The impact of e-learning on students' achievement is complex and depends onmany factors, but studies showed that students learn best with e-learning when interactively engaged in the content(Clark and Mayer, 2011.).

METHOD

This study is focused on four important topics in the grade 8 chemistry curriculum in Bosnia and Herzegovina: structure of matter and states of matter (SSM), pure substances and mixtures (PSM) and on studying effectiveness of teaching strategy with web-based learning material (WBLM), especially designed to connect macroscopic observations with interpretation on submicro level in teaching these concepts.

Study was divided in two parts: a pilot study conducted during 2013 and main study conducted during 2014 and 2015. Purposes of pilot study were to determine students understanding and potential misconceptions regarding structureof matter, to apply WBLM and to see outcomes and practical aspects of its application in school.Results and experiences gained within pilot study served as a base for developing the methodology for main study.

According to curriculum for primary school in Bosnia and Herzegovina, chemistry is taught in 8th and 9th grade. Science, however, is taught earlier within Nature, Biology and Physics. Relevant concepts for chemistry are taught within 7th grade Physics. Therefore we have started pilot study with test of knowledge within 7th grade Physics, regarding concepts of states of matter, phase changes, atoms and molecules. Study continued during 8th grade within Chemistry.

Instruments for data collection were knowledge tests (structure and states of matter, pure substances and mixtures, applied one week after teaching and after three months as delayed test), tests of intellectual ability and questionnaires. In designing instruments we used modified instruments that test conceptual understanding, reading and drawing submicroscopic schemes (Davidowitz et al., 2010), intellectual ability tests: Raven' matrices (Raven, Raven & Court, 2000) and Mill Hill vocabulary test (Raven, Raven & Court, 1998), questionnaire regarding learning motivation (Juriševič, 2010), and students' opinion on chemistry lessons (Juriševič et al., 2010; Vrtačnik, 2010).

Pilot Study

Pilot study started in May 2013 and continued in September 2013. First part of the study (May 2013) included 108 7th grade students from two primary schools in urban region of Sarajevo, while the second part (September 2013 – December 2013) was conducted with 57 8th grade students from this group who attended one primary school.

First part contained test of knowledge in 7th grade Physics. Second part of pilot study included only experimental group with main aim to explore the potential application of web-based learning material and to determine students' achievements and opinions on this new instructional approach.

Teaching SSM and PSM in experimental group was conducted in IT classrooms in selected school. Due to insufficient number of PC's, students were learning in pairs.

Pilot study methodology is presented on Figure 1.

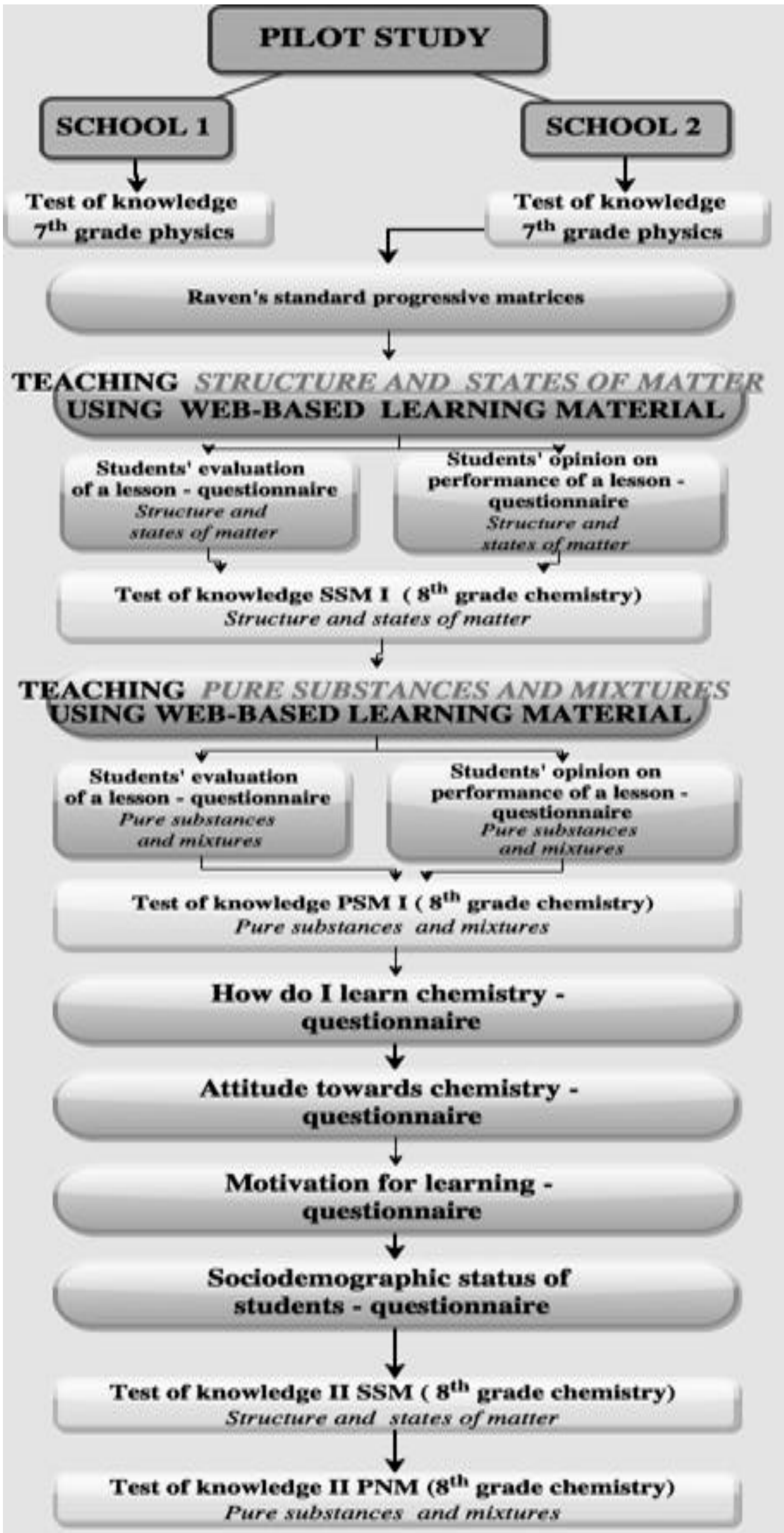

Figure 1: Pilot study methodology

Results and experiences gained within pilot study served as a base for developing methodology for main study. In main study focus is set on further development and testing the teaching strategy with WBLM. Sample includes approx. 210 students aged 13 to 14 years divided in three groups: experimental group 1 (EG1, WBLM applied as homework for students after teaching), experimental group 2 (EG2, students were learning using WBLM on their chemistry classes at school) and control group (CG, taught using textbook (without WBLM) and teacher-centered approach).

RESULTS

Selected Pilot Study Results

Test of knowledge conducted within 7th grade Physics (TK 7th grade) contained nine multiple-choice items regarding concepts relevant to Chemistry.Results of this test revealed some students' misconceptions regarding these concepts (Table 1).

Table 1. List of most frequent misconceptions identified in this study - TK 7th grade

7th grade students misconceptions (N=108)	%
1. We cannot obtain liquid water from water vapor since it disappeared.	28.7
2. We cannot obtain liquid water from water vapor since it has changed.	34.3
3. Bubbles formed when water is heated are made out of gaseous hydrogen and oxygen.	20.4
4. Bubbles formed when water is heated are made out of heat.	44.4
5. Evaporation can shrink water molecules.	41.7
6. Freezing can shrink water molecules.	17.6
7. If we make a leaflet of gold, its atoms become closer to each other.	20.4
8. If we make a leaflet of gold, its atoms become straightened.	28.7
9. Water is composed of hydrogen and oxygen molecules.	34.3
10. Water is composed of hydrogen and oxygen atoms (no chemical bond).	33.3
11. When spilled, water splits up to hydrogen and oxygen.	67.6

We should note that concepts of atom and molecule are taught within Physics for one teaching hour at the end of spring semester, before summer break. These concepts are more extensively taught within Chemistry in the 8th grade, so some preconceptions noted regarding atoms and molecules are somewhat expected, but also addressed during this study.

After processing results of test of knowledge in 7th grade and after teaching selected content (Structure and States of matter) using WBLM in one school (N=57), we have administered test of knowledge regarding taught concepts, both one week after teaching (TK 8th grade-1) and three months after teaching (TK 8th grade-2). These tests were the same, with 10 multiple choice items, similar but not the same to the items in TK 7th grade.

Descriptive statistics of students' achievements is presented in Table 2.

Table 2. Descriptive statistics: TK 8th grade-1 and TK 8th grade-2 (N=57)

	M	SD
TK 8th grade-1	4.04	2.54
TK 8th grade-2	5.27	2.47

Mean and standard deviation for students' achievements shows moderate progress in students' knowledge during three months. When considering retention of students' knowledge, we have noted moderate correlation ($r = .619$, $p>.05$) but also statistically significant difference on TK 8th grade-2 ($t(57) = -2.616$, two-tail $p = .010$).

In addition to TK results, we have processed results of questionnaires for students, regarding their opinion on this new instructional approach. Selected results of these questionnaires for both SSM and PSM are presented in Table 3.

Table 3. Students' perceptions on the use of WBLM

Statement	SSM		PSM	
	M	SD	M	SD
Photos and images helped me in understanding the subject.	4.30	0.84	4.37	0.84
I like having the opportunity to check my understanding.	4.12	0.98	4.04	0.93
I like the explanation of a wrong answer.	3.91	1.10	4.28	0.90
I like the opportunity of going back to the parts that I have not well understood.	4.12	1.04	4.24	0.96
I like using a computer in learning chemistry.	4.16	1.05	4.31	1.00
I'd like to learn more with the help of computers.	4.39	0.97	4.49	0.95
I like learning at my own pace.	3.97	1.01	3.94	0.94

These questionnaires were Likert-type based with scale 1-5 (1-strongly disagree, 5-strongly agree).

DISCUSSION AND CONCLUSION

During pilot study we have encountered with some objective difficulties regarding the time needed for teaching since we needed an IT classroom and PCs. Therefore IT teacher needed to give us her lessons so we could conduct our study. At the same time, chemistry teacher could not teach these concepts again during chemistry lessons. Students were working in pairs due to insufficient number of PCs in classroom and we could not ensure individual approach to teaching content. Therefore we needed to change these aspects of methodology for the main study.

Preliminary pilot study results showed that some phenomena about states of matter students know from everyday experience, but they are not able to explain them on submicro level. Some research already showed comparable findings (Barke et al., 2009; Rappoport & Ashkenazi, 2008; Treagust et al., 2003;Kozma & Russell, 1997).

Results of TK 7th grade administered in May 2013 showed that most students did not differentiate macroscopic and submicroscopic level of the structure and states of matter. Results of both tests of knowledge in 8th grade (TK 8th grade-1 and TK 8th grade-2) showed that even though some misconceptions were noted again, WBLM has a positive impact on students' understanding of particulate nature of matter. Since teacher did not go back with the same teaching content,we presume that explanation for this fact can be possible teachers' intervention after teaching this content and writing test.

In addition, students' perceptions on the use of WBLM were positive. Teaching content did not influence on their perceptions since they gave similar and positive impressions on statements given in questionnaires for both SSM and PSM teaching content. We believe that more frequent use of web-based learning material can enhance students' interest in chemistry and therefore give better results when their knowledge and understanding is considered. Since our students did not perform quite well in external testing (TIMSS 2007), we should be looking for ways to improve our teaching practice.

REFERENCES

Barke, H.-D., Harsch, G., & Schmid, S. (2012). *Essentials of Chemical Education*. Berlin, Heidelberg: Springer-Verlag.

Barke, H.-D., Hazari, A., & Yitbarek, S. (2009). *Misconceptions in Chemistry: Addressing Perceptions in Chemical Education.* Berlin, Heidelberg: Springer-Verlag.

Chittleborough, G. (2014). The Development of Theoretical Frameworks for Understanding the Learning of Chemistry. In Devetak, I. & Glažar S. A. (Eds.), *Learning with Understanding in the Chemistry Classroom*, (pp. 25-40). Dordrecht, Netherlands: Springer Science+Business Media B.V.

Clark, R.C.,& Mayer, R.E. (2011). *E-learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*. 3rd Ed. Pfeiffer: San Francisco.

Davidowitz, B., Chittleborough, G., & Murray, E. (2010). Student-generated submicro diagrams: a useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research and Practice, 11*(3), 154–164.

Devetak, I., Vogrinc, J., & Glažar, S. A. (2009). Assessing 16-Year-Old Students' Understanding of Aqueous Solution at Submicroscopic Level. *Research in Science Education, 39*(2), 157–179.

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's ideas in science*. Philadelphia: Open University Press.

Gabel, D. (1994). Improving Teaching and Learning through Chemistry Education Research: A Look to the Future. *Journal of Chemical Education, 76*(4), 548–554.

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Students' alternative conceptions in chemistry: a review of research and implications for teaching and learning. *Studies in Science Education*, *25*(1), 69–95.

Gilbert, J. K., & Treagust, D. (Eds.) (2009). *Multiple Representations in Chemical Education*. Dordrecht: Springer Science+Business Media B.V.

Johnstone, A. H. (1982). Macro- and micro-chemistry. *School Science Review 64*(227), 377–379.

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response tochanging demand. *Journal of Chemical Education, 70*(9), 701–705.

Juriševič, M. (2010). UM – Vprašalnik za učence osnovne šole. In: *Interim Report V5-0424: Analiza dejavnikov, ki vplivajo na trajnejše znanje z razumevanjem naravoslovno-tehniških vsebin* (pp. 2–5). Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.

Juriševič, M., Vogrinc, J., & Glažar, S. A. (2010). Izvedba učne ure. In: *Interim Report V5-0424: Analiza dejavnikov, ki vplivajo na trajnejše znanje z razumevanjem naravoslovno-tehniških vsebin* (p. 9). Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching, 34*(9), 949–968.

Papageorgiou, G., & Johnson, P. (2005). Do Particle Ideas Help or Hinder Pupils' Understanding of Phenomena? *International Journal of Science Education, 27*(11), 1299–1317.

Rappoport, L. T., & Ashkenazi, G. (2008).Connecting Levels of Representation: Emergent versus submergent perspective. *International Journal of Science Education, 30*(12), 1585–1603.

Raven, J., Raven, J. C., & Court, J. H. (2000). *Manual for Raven's Progressive Matrices and Vocabulary Scales*. *Section 3: The Standard Progressive Matrices*. San Antonio, TX: Harcourt Assessment.

Raven, J., Raven, J. C., & Court, J. H. (1998). *Manual for Raven's Progressive Matrices and Vocabulary Scales*. *Section 5: The Mill Hill Vocabulary Scale*. San Antonio, TX: Harcourt Assessment.

Suzić, N., Saničanin, Ž., Alić, A., Skelić, Dž., Rukavina, D., Alibegović Goro, E., Džumhur, Ž., Šahinović Batista, S., Milinković Rosić, I., Mešić, V., Ibraković, A. (2009, December). *Sekundarna analiza TIMSS 2007 u Bosni i Hercegovini*. Retrieved from http://www.aposo.gov.ba/wp-content/uploads/2012/08/Sekundarna_analiza_TIMSS_2007.pdf

Stieff, M., Ryu, M., &Yip, J. C. (2013). Speaking across levels – generating and addressing levels confusion in discourse. *Chemistry Education Research and Practice, 14*(4), 376-389.

Treagust, D., Chittleborough, G., & Mamiala, T. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education, 25*(11), 1353–1368.

Vrtačnik, M. (2010). Ocena učne ure. In: *Interim Report V5-0424: Analiza dejavnikov, ki vplivajo na trajnejše znanje z razumevanjem naravoslovno-tehniških vsebin* (p. 10). Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.

Wadsworth, B. J. (2004). *Piaget's Theory of Cognitive and Affective Development: Foundations of Constructivism*. Boston, MA: Pearson Education.

CONCEPTUAL PROFILES FOR DOLL'S FOUR R'S

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Abstract: As academic organisers and teachers with different positions teacher training programs at Södertörn University we have had the opportunity to develop and assess different types of pedagogic activities and use, e.g., the 4 R´s proposed by Doll, *recursion, relations, richness,* and *rigor* in assessments. Here pre-service teacher student reflections assessed by use of the 4R's are compared with other texts by the same students in order to assess the quality of their understanding of evolutionary theory. Written performances of biology students are also compared with those of pre-service teacher students in order to reveal differences in the use of scientific concepts between the groups. Analysis of student performances show a relation between the use of the 4R's, and the use of scientific concepts. Analyses of texts by students in evolution theory show a relatively low use of scientific concepts often regarded as important in scientific text. This may be explained by students' good skills in giving scientific explanations in every-day language. Teacher students used more biological and evolutionary concepts compared to biology students. The emphasis on the use of concepts, especially in school, may be exaggerated. Professional biologists have to communicate with people outside the scientific community but teachers often cares about a strict scientific language. This is also found here where teacher students use the concepts to a larger extent than biology students. School biology should focus on the basic processes of organic evolution as the foundation of all teaching in order to enhance the students' deeper understanding.

Keywords: biology, evolution, primary school, concepts

INTRODUCTION

As science teachers at universities for more than 25 years and organisers and teachers in pre-service teacher training programs with an intercultural profile at Södertörn University during the last ten years we have had different opportunities for personal development. Different positions in the management of courses have not only promoted the development and assessment of different types of pedagogic designs in a varied range of courses related to educational sciences, teacher internship and science didactics but also improved and deepened the strategies of our own teaching practice. We have never been that type of teachers who want to communicate all facts and theories they learned themselves, but we have moved from positions were we wanted to communicate specific methods about how to learn. During the years we have experienced a personal improvement towards professional designers of pedagogic events aiming at the encouragement of the students' development towards personal goals out of their possibilities and aspirations.

This personal development has not always been consciously promoted. Sometimes we didn't realise the relations between our early ideas and later findings. For example, Mattsson & Lättman (2004, p. 247) discussed and showed the importance of narrative methods to help students to show their learning outcomes in evolutionary theory. Ten years later Mattsson & Mutvei (2014) showed how open question, which may be regarded as being of a narrative type, gave students better possibilities to show understanding compared to more closed questions, without making any references to the older publication. Similarly, but here with different perspectives, we are today working within the theory of conceptual profiles (Mortimer & El-Hani, 2014). This was anticipated within another theoretical framework in discussions about the need of being interpretative instead of explanatory (Mattsson & Lättman, 2004, p. 247).

In some cases we have been aware of original ideas but never communicated them to our students. After reading Mattsson & Lättman (2004) one of our students exclaimed: “So, the chaos in our courses is consciously organised!” A course should be organized in such a way that it encourages transformation from chaos to personally integrated communicable knowledge. One way of achieving this is to organize some disorder in the system, which needs to resettle in order to continue functioning. (Mattsson & Lättman 2004, p. 246).

The importance of chaos in the learning process is important for Doll (1993), but it is also supported by others like, e.g., Freire (1970, 1975). It also possible to interpret the Vygotskian idea of the proximal learning zone as an example of this. Using the model of Luckner & Nadler (1997, Brown, 2008) the comfort zone may be the zone of total comfort, were nothing new is learned and only old knowledge is preserved or maybe consolidated. The student does exercises on the same level as before without achieving any further skills. The panic zone is governed by such total chaos that it is impossible to start ordering it. In between, the learning zone also contains chaos but it should not be terrifying, but promoting the process of arranging and developing in new direction often without explicit formulated goals.

Markers of quality

Doll’s 4R’s, *richness, recursion, relations* and *rigor*, (Doll, 1993) may be used to evaluate learning (Mattsson & Mutvei, 2014). *Richness* is the ability to see the possibility of many interpretations, *recursion* the ability to make reflections about processes during learning, *relations* the ability to see connections between own experiences, different subjects, cultural events and learning and *rigor* the ability to accept the complexity of indeterminacy and combine it with the hermeneutics of interpretation. Together, the 4R’s show how learning is dependent on the ability to change perspective (Doll, 1993, p. 174–183). The results from the study of Mattsson & Mutvei (2014) may be used for analyses of other performances of the same group of students. Are there differences in the performances of students using the 4R’s in their reflections on the fieldwork and when they are producing other texts in other courses or contexts?

We have also found a correlation between the increased uses of evolutionary concepts on the expense of biological concepts in reflections by students. Further, when analysing the quality of the texts by using *richness, recursion, relations* and *rigor*, texts containing many concepts had most of the 4 R’s indicating a broader knowledge of evolution (Mutvei, et al., 2015). As we have student material from several courses in different programs it may be possible to compare the use of concepts to investigate if this is a general trend and also to relate these texts to the 4R’s.

Visibility of quality markers

The retrospective summary in the introductions represents a teaching context that reveals some important characteristics, although only faintly described. The importance of *relations* in the text above is obvious for most readers but the word occurs only once. The other quality markers *richness, recursion,* and *rigor* (Doll 1993, Mattsson & Mutvei, 2014) are absent in the text as written concepts, but traces of them may be found by the observant reader. This fairly short text gives several examples of similar phenomena from different angles (*richness*), the reflections return to different times and situations (*recursion*), and there is a consequence in its inconsistence as it jumps between different theoretical frameworks (*rigor*).

Thus, the structure of the text above reveals the use Doll´s 4R´s, but the content of the text exposes writers snared in a limited contextual network. The construction of the users’ conceptual profiles of the 4 R's may have visualized their contextual dependence and facilitated the use of them in other contexts.

Similarly, it ought to be possible to reveal the quality of student performances out of their use of scientific concepts. Analyses of students' reflections in order to reveal the quality out of the 4R's (Mattsson & Mutvei, 2014) may be compared with other performances of the same students using the methods of Mutvei et al. (2015).

OBJECTIVES

Thus, the first objective of this study is to investigate the relation between the use of scientific concepts and the conceptual profiles of Doll´s 4 R´s among students. If this relation is positively established, then the second objective is to investigate other texts in order to assess their quality out of the appearance of scientific concepts.

METHODS

The work of Doll was known (Mattsson) since the beginning of 2001 and the theory was used when designing courses for biology students at Södertörn University. This is described by Mattsson & Lättman (2004) together with interpretations of the concepts. Documentation from planning, implementation and evaluation from these courses from 2002 until 2009, when the biology program terminated, was available. Corresponding material from teacher training courses were available from 2008. Further, about 30 publications were available for analysis. In addition a large number of student performances from different courses are available. This material is extensive, texts only referring to the theory of evolution comprises more than 150 000 words and these texts are selected for this study.

Based on the previous results of analyses of the use of the 4R's of Doll (Mattsson & Mutvei, 2014) we investigated the same group of primary school teacher students written examination tasks from a course in evolutionary theory which was held the same semester as they wrote their reflections on the fieldwork. The texts from the evolutionary course were analysed according to (Mutvei, et al., 2015) in order to reveal correspondence between use of the 4R's and scientific concepts.

Further, the students' use of biological and evolutionary concepts in their written exams was studied with comparison between biology students and primary school teacher students (Mutvei, et al., 2015). Here we used texts from four different courses for biology students 2003–2008 and two courses for pre-service teacher students 2008 and 2013.

The texts were searched for scientific concepts and the number of occurrences were recorded. In addition, frequencies of the concepts were calculated and the length of the texts were compared. The results of the two groups, biology and teacher students, were also compared.

RESULTS

Relation between use of the 4R's and other concepts

Teacher students using Doll's 4R in written reflections on their fieldwork use more evolutionary concepts and write longer texts in their examination tasks in evolutionary theory, however, with lower frequencies of the occurring concepts than other students (Table 1).

One group of students using *relations* and *rigor* differs from the others. Almost all of them uses all 4R's and produces longer texts mainly with lower frequencies of evolutionary concepts and also reached a higher mark in their examinations.

Table 1. Students use evolutionary concepts in relation to their use of Doll's 4R.

	All	Any R	Rich-ness	Re-cursion	Re-lations	Rigor	All 4R
n	47	18	17	12	8	8	7
No of used concepts	324	114	113	90	56	79	55
Total no of words	40105	16291	15044	11995	10189	10206	8942
% evolutionary concepts	0.81%	0.70%	0.75%	0.75%	0.55%	0.77%	0.62%
No of words/student	853	905	885	1000	1274	1276	1277
Evolutionary concepts/student	6.89	6.33	6.65	7.50	7.00	9.88	7.86
Relative length	100%	110%	106%	124%	166%	166%	164%
Relative use of evolutionary concepts	100%	87%	95%	112%	102%	157%	117%

Differences in use of scientific concepts between biology and teacher students

Differences in use of specific concepts

Analyses of examinations written by students in different evolution theory courses, four groups in biology and two in teaching show a relatively low use of scientific concepts (Table 2). Here, the biology students show lower frequencies in their use of different scientific concepts compared to teacher students.

Table 2. Student´s use of biological concepts in texts used in examinations related to evolution and phylogeny. Biol = Biology students, (four groups), Biol T = Biology teacher students, PST = Primarys School Teacher students.

Concept	Biol 1	Biol 2	Biol 3	Biol 4	Biol T	PST
n	14	36	3	11	10	47
Adaptation	8	51	8	8	1	50
Development	16	42	18	78	21	97
Environment	27	52	3	52	3	126
Evolution	4	106	45	183	105	214
Family	6	15	8	34	0	9
Gene	0	9	3	55	0	26
Generation	0	50	15	32	3	100
Genus	8	14	3	32	1	10
Hereditary	0	0	2	0	3	3
Heredity	0	1	2	1	0	13
Mutation	0	9	2	17	17	55
Natural selection	0	6	3	4	15	107
Origin	4	5	4	9	1	1
Pool	0	0	0	6	0	1
Population	12	12	15	50	6	67
Random	2	2	0	2	4	51
Selection	0	8	0	18	2	15
Trait	3	63	2	40	4	244
Variation	3	24	4	14	9	101
No of concepts used	93	469	137	635	195	1300
No of words	19820	47012	9642	39426	6726	40105
Percentage of concepts	0.47%	1.00%	1.42%	1.61%	2.90%	3.24%

Differences in use of biological and evolutionary concepts

Teacher students used more biological and evolutionary concepts in general in written exams compared with biology students (Table 3).

Table 3. Students use of biological and evolutionary concepts in texts used in examinations related to evolution and phylogeny.

	Biology students n=64	Teacher students n=57
No of biological concepts used	1334	1495
No of evolutionary concepts used	165	355
No of words	115900	46831
Percentage of biological concepts used	1.15%	3.19%
Percentage of evolutionary concepts used	0.14%	0.76%
% of evolutionary concepts out of biological	12.37%	23.75%

Differences in use of specific evolutionary concepts

Also the use of different evolutionary concepts differ between the groups (Table 4).

Table 4. Students use of evolutionary concepts in texts used in examinations related to evolution and phylogeny.

	Biology students n=64	Teacher students n=57
Adaptation	75	51
Natural selection	13	122
Random	6	55
Selection	26	17
Variation	45	110
Total no	165	355

DISCUSSION

The first analysis of student performances show a relation between the use of the 4R’s, especially *relations* (n=8), *rigor* (n=8) and all 4R’s (n=7) the use of scientific concepts. These students have low relative frequencies of evolutionary concepts. This may be explained by a better understanding and ability to explain in every-day language. This indicates ability to see the possibility of many interpretations (*richness*), to make reflections (*recursion*), to see connections (*relations*), and to accept complexity (*rigor*).

Analyses of examinations written by students in evolution theory courses show a relatively low use of scientific concepts often regarded as important in scientific text, although many of them, according to their marks (not shown here), show good knowledge of evolutionary theory (Table 2). This may also be explained by these students’ good skills in giving scientific explanations in every-day language.

Teacher students used more biological and evolutionary concepts in written exams compared to biology students (Tables 3 and 4). Also here the explanation may be similar to the previous. Biology students, often with deeper understanding of the theories, may have it easier to describe their content compared to teacher students. In addition, the professional biologist have to know how to communicate with the general public, while the teacher often is locked in the world of school science where the use of concepts is regarded as an important skill.

The emphasis on the use of concepts, especially in school, may be exaggerated. For the professionals it is usually important to communicate with people outside the scientific community and they have to have the ability to use a non-scientific language. It is important not only to know the concept and its' definition but also to have the ability to use it in different situations. A necessary condition for this is good understanding of the reality behind the concepts. Otherwise it is hard to change perspectives and explain it in other contexts.

School biology should focus on the basic processes of organic evolution as the foundation of all teaching in order to enhance the students' deeper understanding.

REFERENCES

Brown M. 2008 Comfort Zone: Model or metaphor? *Australian Journal of Outdoor Education* 12(1), 3-12.

Doll, W. E., Jr. (1993). *A post-modern perspective on curriculum*. New York: Teacher College Press.

Freire, P. (1970). *Pedagogy of the oppressed*. New York & London: Continuum.

Freire, P. (1975). *Education for critical consciousness*. New York & London: Continuum.

Mattsson, J.-E. & Lättman, H. 2004. Chaos and order in teaching and research. *Acta Univ. Ups. Symb. Bot. Ups*. 34:1, 245–255. Uppsala.

Mattsson, J.-E, & Mutvei, A. (2014) Aim: To practise scientific methods. Result: Personal development.. In Constantinou, C. P., Papadouris, N. & Hadjigeorgiou, A. (Eds.) *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning Part 13* (co-ed. Avraamidou, L. and Michelini, M.) (pp. 188-195) Nicosia, Cyprus:

Mortimer, Eduardo F., El-Hani, Charbel, N. (Eds.) (2014) *Conceptual Profiles, A Theory of Teaching and Learning Scientific Concepts*, Springer

Mutvei, A., & Mattsson, J.-E. (2014) How to Teach Evolution. *Procedia - Social and Behavioral Sciences* Vol.167:170–177, The XVI International Organisation for Science and Technology Education Symposium (IOSTE Borneo 2014)

TRACING STUDENTS' IDEAS ON HOW PREDICTABLE NATURE MAY BE AND WHY

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Abstract: This paper is part of a larger study aiming at the development of a two-tier data-gathering tool for exploring students' views about the predictability of nature's response to disturbance/protection. We report here the results of a case study conducted with the current version of our tool and our focus is set on (a) how predictable educational sciences students think ecosystems are, and (b) how they justify the degree of predictability they attribute to disturbed/protected ecosystems when provided with certain options. Ninety-two educational sciences master-students completed the current version of a two-tier questionnaire, developed during four pilot studies and consisted of 11 items, 9 of which concern us here. From students' choices, justifications and verbal/written comments in the first two pilot studies – where we used an earlier version of the questionnaire with fixed alternative choices and free justifications – six categories of reasoning about the ecosystems' predictability arose. Using these categories we composed a two-tier questionnaire consisted of a first tier where students answered about the predictability of the ecosystem on a four-item Likert scale, and a second tier where they justified their answers by choosing from a list of six alternatives or writing their own. Early versions of this questionnaire were used for our third and fourth pilot studies with students and educational researchers, respectively. Considering the feedback we had, we came up with the current version which we used in the case study we report here. The analysis of students' responses suggests that they averagely don't believe strongly neither in a predictable nor in an unpredictable nature. When trying to explain the ecosystems' predictability/unpredictability, most students use the assumptions of a globally-unstable nature, while many use those of a globally-stable nature instead. Finally, only few seem to appeal to the currently more valid view of a resilient nature.

Keywords: ecological reasoning; nature's predictability; two-tier questionnaire

INTRODUCTION

Ecosystems are complex and dynamic systems (Ladle & Gillson, 2009); in the light of current ecological research nature is not considered as constant and balancing, but as constantly changing in both time and space in non-linear contingent ways (Gunderson, Allen, & Holling, 2010). Nevertheless, although criticized as not representative of natural systems (Cuddington, 2001; Kricher, 2009), the idea of a 'balanced nature' seems to be rather widespread in school science (Jelinski, 2005; Korfiatis, Stamou, & Paraskevopoulos, 2004) and popular culture (Ladle & Gillson, 2009). Is this 'mismatch' between researchers and public opinion something one should worry about?

The ideas people hold concerning ecosystems' function, and more specifically their response to disturbance or protection, play a significant role in public debate about environmental issues (e.g. climate change, sustainability), which requires from citizens to make informed decisions concerning nature (Westra, 2008). This essential, contemporary need has shifted the goal of science education from preparing future scientists to preparing future, scientifically literate citizens (Assaraf & Orion, 2005). The development of scientific literacy gets more important when it comes to pre-service teachers, as their assumptions may influence the beliefs of their students as well.

How do pre-service teachers reason about the ecosystems' response to disturbance or protection? Dealing with scenarios of ecosystems suffering disturbances, educational sciences students were frequently found to believe in a certain or possible full/partial recovery, while they rarely suggested that ecosystems wouldn't recover at all (Ampatzidis & Ergazaki, 2014; Ergazaki & Ampatzidis, 2012). Moreover, students were frequently found to believe that protected ecosystems would certainly or possibly remain the same over time, while some of them claimed a different or possible different picture for such ecosystems (Ampatzidis & Ergazaki, 2014; (Ergazaki & Ampatzidis, 2012). Finally, they very rarely suggested that it wasn't feasible to make predictions about their future (Ergazaki & Ampatzidis, 2012).

In both studies, some students seemed to suggest that there is a degree of uncertainty about the future of disturbed/protected ecosystems. Nevertheless, this uncertainty was rarely based on the idea of an intrinsic unpredictability of the ecosystems (Ergazaki & Ampatzidis, 2012). Since we think that students' views about whether and why nature's response to disturbance or protection may be predictable are worth exploring in a large scale, we are in the process of developing a two-tier data-gathering tool (Tan, Goh, Chia, & Treagust, 2002; Treagust, 1988; Tsui & Treagust, 2010) for a future use in a survey with students of different countries.

In this paper, we report the results of a case study conducted with the current version of our tool. Our focus is set on students' ideas on nature's predictability. The research questions we address are:

(a) 'How predictable ecosystems may be according to students of educational sciences?'.
(b) 'How do students justify their views about the degree of predictability they attribute to disturbed/protected ecosystems when provided with certain options?'.

METHODS

Students participating in the fifth case study (CS5) presented here as well as in the previous four pilot studies (CS1-4) have majors in different fields and are currently following educational sciences master-studies (pre-service primary school education). The data-gathering tool we used in CS5 was the fifth version of a two-tier questionnaire developed during CS1-4. The scenarios of this tool as well as the scenarios of its previous versions are summarized in Table 1. There were also scenarios relevant to social systems which are out of focus here.

Table 1. Participants and scenarios of the case studies (CS).

	CS1	CS2	CS3	CS4	CS5
Questions type	Closed-ended questions/ open-ended justification	Closed-ended questions/ open-ended justification	Two-tier closed-ended questions	Two-tier closed-ended questions	Two-tier closed-ended questions
Participants	22 students	77 students	38 students	42 edu researchers	92 students
Scenario 1	Protected forest				
Scenario 2	Introduction and subsequent removal of a population in a lake				
Scenario 3		Introduction and subsequent removal of nutrients in a lake			
Scenario 4		Forest fire			
Scenario 5					Oil spill in the sea and subsequent removal of the oil
Scenario 6					Flooding of a meadow and subsequent retreat of the water
Scenario 7					Arrival of a new population in a forest and subsequent departure
Scenario 8					Disappearance of a population in a river caused by a fatal illness and subsequent re-introduction
Scenario 9					Decline of a fish population and subsequent fishing regulation

CS1-2 were conducted with the purpose of developing the alternative answers of our tool's second tier. In CS1-2, students dealt with scenarios concerning disturbed/protected ecosystems and answered about their predictability and future in closed-ended questions developed on the basis of previous research (Ampatzidis & Ergazaki, 2014; Ergazaki & Ampatzidis, 2012). Students had to justify their answers in an open-ended part and were also asked to make written/verbal comments on the questionnaire during and after its completion.

From students' choices, open-ended justifications and their comments in CS1-2, six categories of reasoning about the ecosystems' predictability arose. We used these categories to compose the alternative answers of a two-tier questionnaire which was delivered for CS3: in the first tier students answered about the predictability of the ecosystem on a four-item Likert scale and in the second tier they justified their answers by choosing from a list of six alternative answers or writing their own.

The fourth version of our questionnaire was developed by considering the feedback we had and adding new scenarios aimed at testing different variables (e.g. human-driven/natural type of disturbance). This version was delivered to educational researchers in the context of CS4 and, based on the relevant feedback we received, we finally developed the fifth version of the questionnaire that was delivered to 92 students for CS5 that we present here. In Table 2, there is an example of the alternative answers of the second tier.

Table 2. Example of the alternative answers of the second tier (scenario 3 of CS5).

Alternative answer 1	I can predict that, several years after the restore of the amount of nutrients, the lake will return to its initial state (namely the one it had before the introduction of the excessive nutrients)
Alternative answer 2	I can predict that, several years after the restore of the amount of nutrients, the lake will be different comparing to how it initially was (namely how it was before the introduction of the excessive nutrients)
Alternative answer 3	I cannot really predict but I think that, several years after the restore of the amount of nutrients, the lake will be close to its initial state (namely the one it had before the introduction of the excessive nutrients)
Alternative answer 4	I cannot predict because I have no idea
Alternative answer 5	I cannot predict because I think it is impossible to predict
Alternative answer 6	I think that, several years after the restore of the amount of nutrients, the lake will be different comparing to how it initially was (namely how it was before the introduction of the excessive nutrients), but I cannot predict to what way it will be different
Other:	*(Free answer)*

Scores 1-4 were assigned to Likert scale items ranging from 'I can predict' to 'I cannot predict' respectively. To test the questionnaire's reliability, we calculated Cronbach's alpha coefficient for the total of students' answers in the first tier. For the following analysis we disregarded all answers that (a) were not followed by a choice in the second tier and (b) were followed by the choice 'I have no idea' in the second tier. We did so with the purpose to exclude the replies that were not justified or were driven by a mere unfamiliarity with the question. Moreover, we detected seven open-ended answers in the second tier which we recoded to the six alternative answers already existed.

Finally, we tried to correspond students' responses in the second tier to the views of nature suggested by Gunderson et al. (2010). The three views of nature they suggest are the following:

- 'Balanced Nature': nature is globally stable; if nature is disturbed, it will return to an equilibrium through negative feedback processes. Alternative answers 1 and 3 are related to this view.
- 'Anarchic Nature': nature is globally unstable; it is dominated by positive feedback processes and hyperbolic processes of growth and collapse. Alternative answers 2 and 6 are related to this view.

- ‘Resilient Nature’: nature exists in multi-stable states which may shift abruptly when certain tipping points are reached; it is organized by both positive and negative feedback processes, discontinuous events and nonlinear processes. Alternative answer 5 is related to this view.

RESULTS

Regarding the first tier, the mean of students’ choices on the Likert scale was 2,504 with a standard deviation of 1,018. Since the score of students’ choices ranged from 1 to 4, it seems that the students who filled our questionnaire averagely don’t have a strong belief neither in a predictable nor in an unpredictable nature. The Cronbach’s alpha coefficient was calculated to 0,79.

Regarding the second tier, the most popular answer seems to be the answer according to which the ecosystems will be different after the disturbance or regardless the protection but it is not predictable in what way (answer 6) (Figure 1). The second most popular is the answer according to which the ecosystem, after the disturbance or regardless the protection, will be quite predictably different comparing to how it initially was (answer 2). Finally, the least popular answer is the answer which recognizes an inherent incapability to predict the future of an ecosystem which is disturbed or protected (answer 5) (Figure 1).

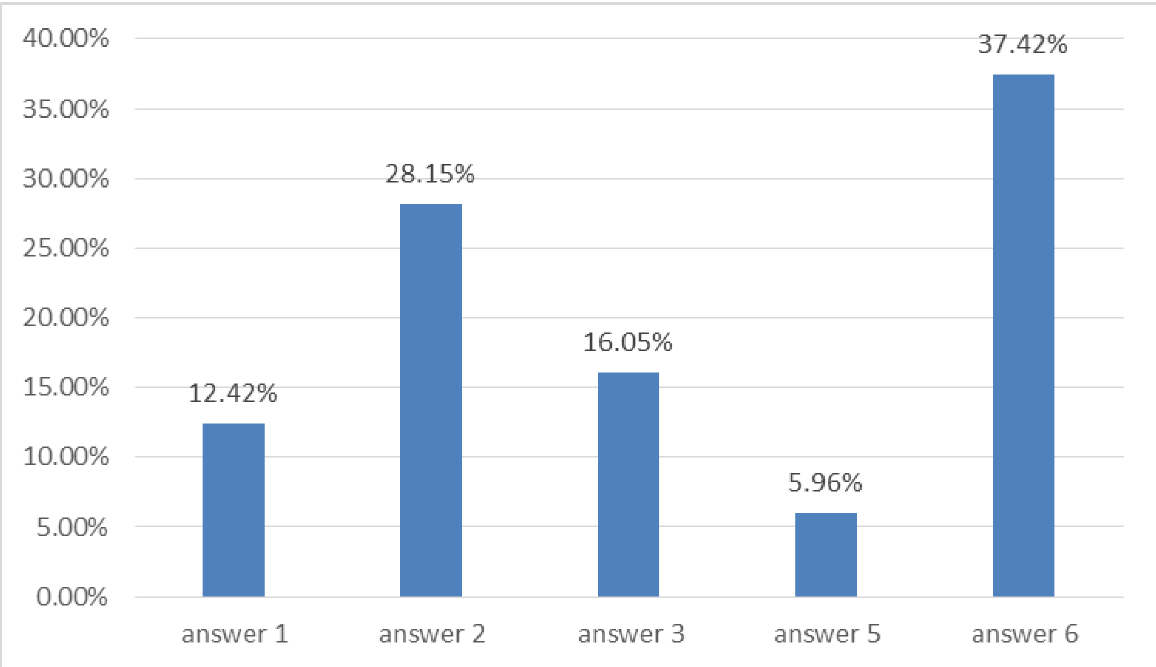

Figure 1. Percentages of the alternative answers on the second tier of CS5.

Moreover, our coding on the basis of Gunderson et al. (2010) showed that the ‘anarchist’ view of nature is dominant in the participants’ reasoning (Figure 2): answers 6 and 2 which are related to this conceptualization of nature were the ones with the highest frequencies. On the other hand, the ‘resilient’ view of nature was very little appealing among the students that filled our questionnaire: answer 5 which is related to this conceptualization of nature was the one with the lowest frequency of all (Figure 2).

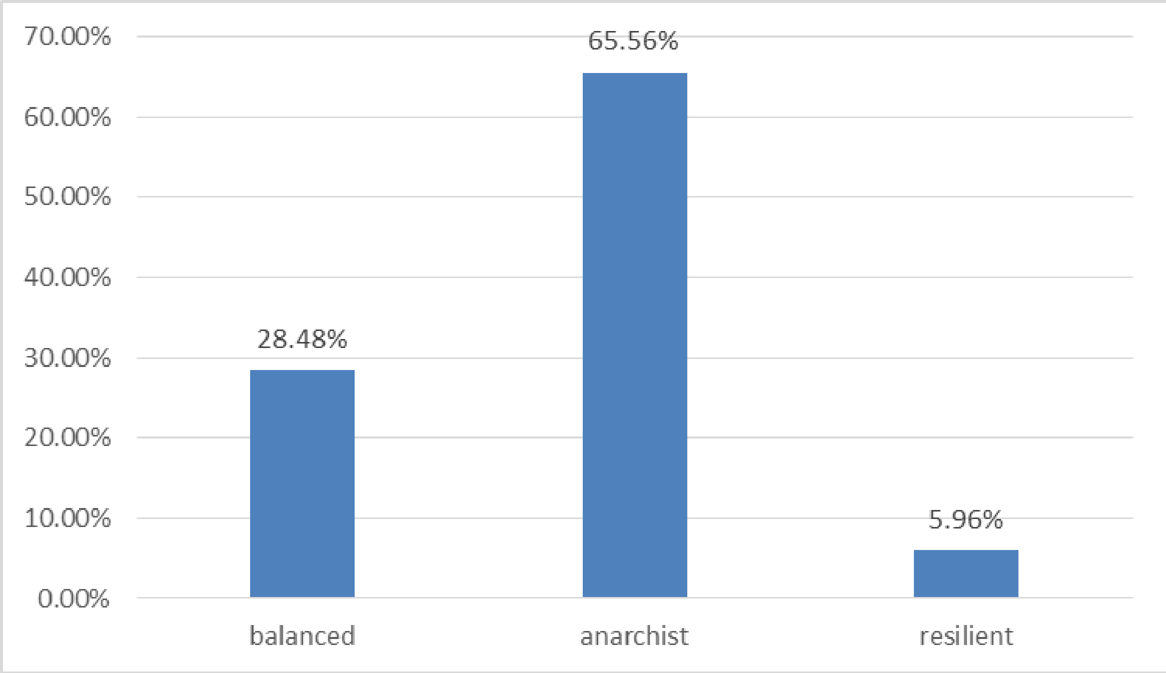

Figure 2. Percentages of the 'nature views' (Gunderson et al., 2010) according to the answers on the second tier of CS5.

DISCUSSION

Students seem to be 'moderate' in their ideas about the predictability of nature; when asked about how predictable ecosystems may be they averagely appear to believe in a nature that is neither strongly unpredictable nor strongly predictable.

Moreover, considering students' responses, we might argue that the idea of nature's predictability can be contradictory in their minds. More specifically, the majority of students seem to think that (a) an ecosystem which undergoes a disturbance won't recover, even in the case there is a subsequent human-driven effort to restore it, and (b) that an ecosystem which is protected will, nevertheless, be different after some time; in both cases, students argue that it is unpredictable how different these ecosystems may be. In other words, their responses suggest that they can actually predict that an ecosystem will be different after a disturbance or regardless its protection, but they claim they cannot predict in what way.

Finally, regarding the ways they explain ecosystems' predictability/unpredictability using the views of nature according to Gunderson et al. (2010), most students use the assumptions of the 'anarchist-nature' view, while many use the assumptions of the 'balanced-nature' view instead. It seems that most students believe in a globally unstable nature driven by positive feedback loops, while many of them believe in a globally stable nature driven by negative feedback loops. Only a few students reason about ecosystems' predictability by appealing to the currently more valid view of the 'resilient-nature', which assumes that nature may exist in more than one stable states driven by stochastic events and nonlinear processes, to reason about ecosystems' predictability.

These conceptualizations of nature may have impact on students' environmental reasoning, as well; they may interfere with the ways they possibly think about the preservation of nature: (a) believing in a globally unstable nature ('anarchist nature'), one assumes that the use of technology is eventually catastrophic for the environment and the purpose of environmental policy should be the maintenance of the status quo (Gunderson et al., 2010) and (b) believing in a globally stable nature ('balanced nature') may undermine the significance of not disturbing ecosystems implying their almost 'magical' power to recover initial state (Westra, 2008). In both cases, the relevant assumptions about nature's function may hinder environmental awareness, along with conceptual understanding as already explained. Such results (a) underline the need for developing teaching materials and ways of instruction in order to challenge scientifically controversial views of nature such as the 'anarchist nature' and the 'balanced nature' and construct a meaningful understanding about how ecosystems may function, and (b) offer some insight on ideas that should inform such development.

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REFERENCES

Ampatzidis, G., & Ergazaki, M. (2014). Towards a learning environment for challenging the idea of the balanced nature: Insights from the first cycle of research. In C. P. Constantinou, N. Papadouris, & A. Hadjigeorgiou (Eds.), *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning. Part 3* (pp. 44–54). Nicosia, Cyprus: European Science Education Research Association.

Assaraf, O. B.-Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching*, *42*(5), 518–560.

Cuddington, K. (2001). The "Balance of Nature" Metaphor and Equilibrium in Population Ecology. *Biology and Philosophy*, *16*(4), 463–479.

Ergazaki, M., & Ampatzidis, G. (2012). Students' Reasoning about the Future of Disturbed or Protected Ecosystems & the Idea of the "Balance of Nature." *Research in Science Education*, *42*(3), 511–530.

Gunderson, L. H., Allen, C. R., & Holling, C. S. (Eds.). (2010). *Foundations of Ecological Resilience*. Washington, DC: Island Press.

Jelinski, D. E. (2005). There is no mother nature-there is no balance of nature: culture, ecology and conservation. *Human Ecology*, *33*(2), 276–285.

Korfiatis, K. J., Stamou, A. G., & Paraskevopoulos, S. (2004). Images of nature in greek primary school textbooks. *Science Education*, *88*(1), 72–89.

Kricher, J. (2009). *The balance of nature: Ecology's enduring myth*. Princeton, NJ: Princeton University Press.

Ladle, R. J., & Gillson, L. (2009). The (im)balance of nature: a public perception time-lag? *Public Understanding of Science*, *18*(2), 229–242.

Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust, D. F. (2002). Development and application of a two-tier multiple choice diagnostic instrument to assess high school students' understanding of inorganic chemistry qualitative analysis*. *Journal of Research in Science Teaching*, *39*(4), 283–301.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education*, *10*(2), 159–169.

Tsui, C.-Y., & Treagust, D. (2010). Evaluating Secondary Students' Scientific Reasoning in Genetics Using a Two-Tier Diagnostic Instrument. *International Journal of Science Education, 32*(8), 1073–1098.

Westra, R. (2008). *Learning and teaching ecosystem behaviour in secondary education*. Castricum, Netherlands: Faculteit Betawetenschappen.

IDENTIFYING MISCONCEPTIONS AND DIFFICULTIES TO DESIGN A LEARNING PROGRESSION IN GENETICS

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Abstract: Identifying misconceptions and difficulties encountered by students in learning a topic is a crucial step which should precede the design of any learning progression-driven curricular unit. Consequently, the purpose of this study was to investigate students' misconceptions and difficulties in genetics, an important yet difficult topic, in an attempt to design a curriculum that would enhance student understanding of genetics. Using quantitative and qualitative data-collection methods, we obtained an in-depth understanding of the nature of misconceptions and difficulties encountered by Grades 7-12 students, determined the level of their genetic literacy, and explored the progression of the level of conceptual understanding of major genetics concepts across grade-levels. A questionnaire was administered to 729 students (G7-12) in 6 schools and was followed by interviews with 62 students to validate the questionnaire results, gain further understanding of students' misconceptions, and assess their level of genetic literacy. Findings showed that patterns of inheritance, the deterministic nature of genes, and the nature of genetic information were among the most difficult concepts. Students also had inadequate understanding of gene-trait relations. However, there was growth in understanding some genetics concepts as grade levels advanced. Furthermore, students across all grade levels showed low levels of genetic literacy as evidenced by minimal understanding of real-life examples like hybridization, genetic engineering, and polygenic traits. Implications for practice and research are discussed.

Keywords: conceptual understanding, genetics, genetics literacy, misconceptions

INTRODUCTION

Recently, there is growing interest in research-based curriculum reform where students' difficulties, correct conceptions, and incorrect conceptions (misconceptions) are advocated as vehicles for refining curricula and ensuring a better alignment between instructional objectives, pedagogical strategies, and assessment (Maskiewicz & Lineback, 2013). This recognition constitutes the cornerstone of developing learning progressions (LPs) that are used to design instructional materials to enhance student learning (Hadenfeldt, Bernholt, Liu, Neumann & Parchmann, 2013).

Research studies revealed common genetics topics in which students encounter difficulties and hold misconceptions (e.g. Lewis & Wood-Robinson, 2000; Lewis & Kattmann, 2004; Duncan & Reiser, 2007; Haambokoma, 2007; Mills Shaw, Horne, Zhang, & Boughman, 2008), and uncovered possible sources and origins of these misconceptions (e.g. Castéra et al., 2008; Donovan & Venville, 2014; Duncan & Reiser, 2007; Lemke, 1990; Lewis & Wood-Robinson, 2000; Lewis & Kattmann, 2004). Results of these studies have been used to design genetics LPs (e.g. Duncan, Rogat, & Yarden, 2009; Roseman Caldwell, Gogos, & Kurth, 2006).

In conjunction with other researchers, we believe that identifying the common misconceptions and difficulties encountered by G7-12 Lebanese students in learning genetics and determining their genetics literacy constitute the initial steps for developing a genetics learning progression and more comprehensive genetics units that foster better learning. With the Lebanese Curriculum being currently under revision and teachers highlighting the importance of contextualized research, this study considered the conceptual understanding, difficulties, and misconceptions Grade 7-12 Lebanese students encounter in studying genetics rather than building on research investigated in Western countries. It is worth noting that this paper is part of a larger research study whose purpose was to design and validate a genetics learning progression and LP-driven unit (the development and authentication will be presented in future papers).

While biology teachers claim that Lebanese students hold the same misconceptions across grade levels, there are currently no empirical studies which identify the type(s) of misconceptions that might impair students' understanding or investigate the progression in students' level of conceptual understanding of major genetics concepts across G7-12. Consequently, we sought to (1) investigate the misconceptions and difficulties encountered during genetics instruction, (2) examine the progression in the level of student understanding of major genetics concepts across grade levels, (3) determine students' level of genetics literacy, and (4) explore students' perspectives on improving the genetics curriculum.

METHODOLOGY

This study adopted a descriptive mixed-methods design. Quantitative and qualitative data collection methods were used to explore variations in the level of conceptual understanding of major genetics concepts across grade levels and obtain an in-depth understanding of the major misconceptions and difficulties encountered by G7-12 students enrolled in three private and three public schools that use the same national textbook. Participating schools were located in three geographic regions in Lebanon. Two sections were randomly drawn from each of the grade levels 7-12 at each of the schools resulting in a total of 729 students for participation in the study.

A questionnaire constructed by the researchers based on an extensive literature review (including standards identified by AAAS project 2061) and the learning outcomes identified by the Lebanese Center for Educational Research and Development (CERD) was validated by 5 biology educators and piloted with 100 students from two public and two private schools that were different from those participating in the study. Necessarily modifications were made and the final version of the questionnaire consisted of 38 items: 9 items provided data on student background (school, age, gender, grade level, etc.); 12 items assessed student's opinions about the existing genetics curriculum and addressed genetics misconceptions using a 5-point Likert-type scale; 11 ordered-multiple choice (OMC; Fig.1) items identified students' level of conceptual understanding in specific genetics concepts; and 6 open-ended items addressed students' level of genetics literacy and understanding of major genetics concepts.

The OMC items (see Figure 1) feature a set of correct response options, where each response is linked to a discrete level of conceptual understanding: low (level 1), average (level 2) or high (level 3). The option "*I don't know*" was also included.

A child suffering from Down's Syndrome has 47 chromosomes instead of 46 chromosomes. He has an extra copy of chromosome 21. How is this explained?

- **a.** This child inherited 2 copies of chromosomes 21 from one parent and one copy of chromosome 21 from another parent.
- **b.** The homologous pair chromosome 21 fails to separate during meiosis in one of the parent producing a sex cell with two copies of chromosome 21.
- **c.** The cells of this child underwent DNA duplication resulting in three copies of chromosome 21

Figure 1. **An example of ordered-multiple choice (OMC) items.**

The same questionnaire was administered to students during a 50-minute biology class by the end of April to ensure that all students have studied genetics. Although G7-8 students do not study genetics, they were included in the sample to uncover any prior knowledge acquired from informal sources (media, family, etc.).

Means, standard deviations, frequencies, and percentages were used to analyze students' responses to multiple choice items. Percentages of correct/incorrect responses were compared across grade levels. Chi-square tests for each item determined whether variations in student responses were statistically significant and one-way ANOVAs verified whether students' level of misconceptions differed across G7-12. Two researchers analyzed students' open-ended responses using categories of genetics misconceptions identified by Mills Shaw et al. (2008). Discrepancy in classification was discussed until consensus was reached. Inter-rater agreement was 95%.

Students at a certain grade level were considered to be highly genetically literate if at least 80% of them were able to answer more than 80% of the questions correctly, or having an average level of genetics literacy if the percentages were 60-80%, or of a low level of genetics literacy if the percentages were less than 60%.

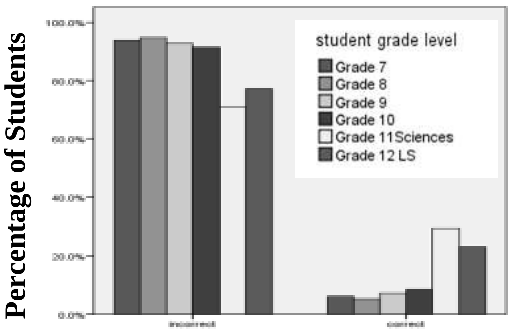
Additionally, 62 students were randomly selected from all grade levels to participate in semi-structured interviews (11 open-ended questions) which required students to explain real-world genetics phenomena, determine their positions on the genetics curriculum, and suggest means for improving genetics instruction. Interviews were carried out in English by one of the researchers and lasted 25-30 minutes each. All interviews were tape-recorded, transcribed, coded, and categorized by a researcher, an experienced biology teacher, and an assistant researcher to determine similarities and/or differences in students' responses. Disagreements were discussed until consensus was reached. Inter-rater agreement was 90%.

RESULTS

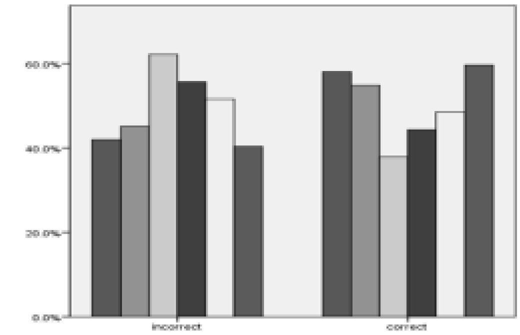
In this section, findings drawn from students' responses to both the questionnaire and interviews will be presented as they pertain to each of the four research objectives.

1. Students at all grade levels exhibited high levels of misconceptions (79.3-94.0%), showed inadequate understanding of major genetics concepts (e.g. polygenetic inheritance, differences between gene and allele, environment's role in modifying phenotypes, genetic origin of diseases), and revealed a low level of progression in their conceptual understanding of major genetics concepts across grade levels (Figure 2; Tables 1 & 2).

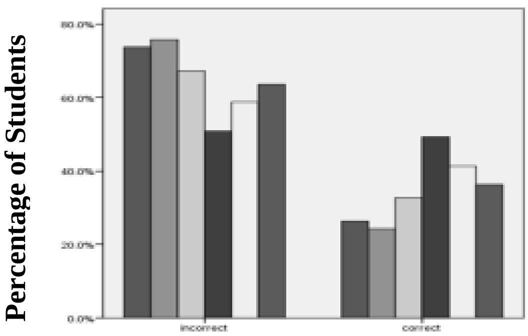
2. One-way ANOVA indicated that the level of misconceptions in genetics is highly influenced by grade level as indicated by a statistically significant difference in the mean scores of the six different grade levels at the $p<.05$ level [F (5, 723) = 7.68, $p<.01$].



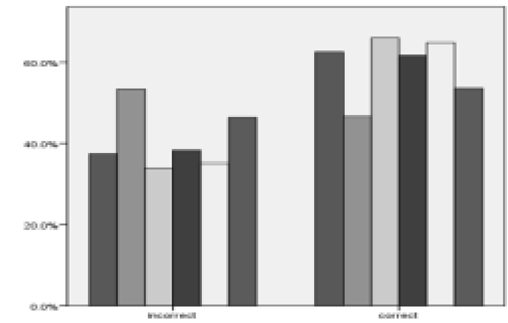
Item 16: Change in DNA is always expressed and leads to harmful consequences on an individual



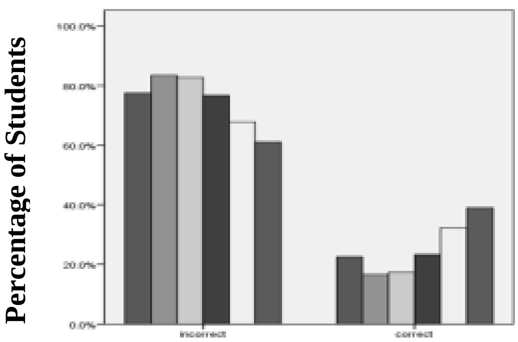
Item 17: Different cell types found in an individual's body contain different DNA



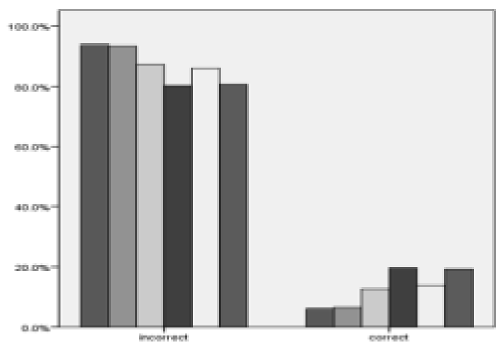
Item 18: Information in the DNA of a human does not affect the behaviors of the human.



Item 19: Like humans, plant cells and fungi have genes that determine their traits.



Item 20: Each cell contains only the specific genetic information required for its function.



Item 21: All diseases which have genetic origin are hereditary diseases

***Figure 2.* Percentage of students with correct and incorrect responses across grades levels.**

Table 1.

Students' Conceptions of DNA, Chromosomes, Genes, and Traits across Grade Levels

Grade level	Students' conceptions and misconceptions	
7	- DNA contains information about one's body. - Chromosome is something carrying information inside a DNA. - Genes form chromosomes.	- Genes show the characteristics or traits of a person. - DNA determines person traits. - ***DNA is a test.*** It helps identify paternity hood and family relations.
8	- DNA is used to identify the identity of individual. - Genes determine eye color, body form. - ***Brain determines my traits.*** - My height is determined by glands. - DNA is a structure in the cell. It helps us determine blood group.	- ***DNA is a test for our origin.*** - Different DNA determines different traits. - ***Chromosomes mean abnormalities.*** - ***Traits are determined by Go or parents*** - DNA helps show relation with relatives.
9	- ***DNA is a test.*** - Chromosomes and ***karyotype determine my traits.*** - Karyotype is used to determine whether we look like our mother or father. - ***Alleles are inside genes.*** - ***DNA is a blood test*** to detect parenthood. - Different traits are determined by different alleles.	- ***A gene is found on a chromosome*** and carries information. - ***Genes determine traits & DNA determines identity.*** - ***Each cell exists in a location that changes its function.*** - ***Finger print is part of skin.***
10	- Gene is one pair of chromosome, while DNA is all the chromosome. - ***Chromosomes carry DNA & Genes hold alleles.*** - ***DNA is the test used to determine paternity hood and relationship.*** - ***Height is inherited from my father.*** - ***Gene is a trait found on a chromosome and chromosomes make DNA.***	- ***DNA is a sequence of genes.*** - ***DNA is related to characteristics, but I don't its structure.*** - ***DNA is information from parents.*** - ***Genes determine traits but I don't know how.***
11	- DNA is a double helix containing nucleotides ***coiled around an axis of chromosomes.*** - Gene is a segment of DNA. - Chromosomes hold the genes & DNA holds specific characteristics. - ***Each chromosome codes for one molecule of DNA.*** - ***DNA is a section of chromosome. A gene is the trait on chromosome and it's a DNA segment.*** - ***DNA is a protein and chromosomes are made up of DNA.***	- ***DNA is a small part of chromosomes and gene is part of DNA.*** - ***Genes make DNA, DNA makes proteins and proteins form the genotype and the genotype determines phenotype.*** - ***DNA is found in the gene.*** - ***Gene is inside chromosome, DNA is inside gene and alleles are formed of genes.*** - ***DNA is a protein and DNA identifies pedigrees.***
12	- Genes make up DNA and DNA makes chromosomes.	- Gene is part of DNA and DNA is part of chromosome.

*Major common misconceptions are in bold and italics.

Table 2.

Conceptual change on the cause of albinism: Statements expressed by students

Grade Level	Statements
Grade 7	✓ I don't know ✓ Its inherited from parents ✓ It's due to a ***white gene*** ✓ Albino people don't sit in the sun. ✓ These people have cells different from ours, they have no color but I can't explain why ✓ These people have ***excessive vitamin C***
Grade 8	✓ I don't know ✓ It's inherited from parents ✓ ***Due to lack of calcium and nutrients taken*** by the pregnant mother. ✓ Due to weak immunity. ✓ Skin cells of albino people don't absorb sunrays when exposed to UV radiations
Grade 9	✓ I don't know ✓ It's due to a gene inherited from parents. ✓ It's due to an allele ✓ Wrong medication taken by the pregnant woman ✓ Errors in the chromosome ✓ ***Due to influence of nuclear bomb on genes***
Grade 10	✓ ***I don't know*** ✓ ***Maybe, but I don't know how*** ✓ Yes, for example sport and physical exercises (environment) can affect my height ✓ Yes, sometimes, the food taken by my father might affect a gene, and this is transmitted to me. ✓ Yes, skin cancer is induced by UV radiations**. *UV light weakens the skin which becomes more prone to infections***
Grade 11	✓ No, ***except during fetal development*** where mutation might occur ✓ Yes, But ***I can't explain how*** ✓ Yes, some chemicals in polluted areas can cause lung diseases. However, I can't explain the mechanism. ✓ Yes, ***cold environment can cause bigger noses.*** ✓ Yes, insufficient food supply can harm people. ✓ Probably, because X-rays and nuclear weapon can cause changes but on the long run.
Grade 12	✓ ***No, there is no effect*** ✓ Yes, environment affects genes. Exposure to sun can cause skin cancer by affecting the genes. ✓ Yes, X-rays, pollutants… can cause mutation and lead to abnormalities. ✓ Yes, African people have dark skin, Lebanese people have white skin ✓ Yes, ***moth which have a dominant white color turns black under the effect of pollution in the environment!!!!!!!!!***

*Major common misconceptions are in bold and italics.

3. Students at all grade levels showed a high level of conceptual understanding (Table 3).
4. Chi-square analyses on each of the items were significant (*p*<.05) indicating a statistically significant difference in students' levels of conceptual understanding across grades 7 to 12.

Table 3.

Percentages for the Level of Conceptual Understanding for Items 23-33

Item	Level 1 (%)	Level 2 (%)	Level 3 (%)	Don't know (%)
23. Which statement is true about these body cells?	27.3	19.5	45.3	7.8
24. Relationship between a gene and a trait	38.8	21.3	26.3	13.6
25. Cause of muscular dystrophy	14.8	20.3	20.3	8.4
26. Concept of alleles on homologous chromosomes	12.5	20.6	58.3	8.6
27. What determines height	26.9	24.6	38.1	10.4
28. Genetic predisposition of breast cancer	11.8	21.1	59.3	7.8
29. Relationship between chromosomes, DNA and molecules	26.7	26.6	23.5	23.2
30. Genetic information in the body cells of son and parent	16.5	30.0	43.9	9.6
31. Heritable mutation	24.1	34.4	25.7	15.8
32. Explaining Down Syndrome in a child	17.7	28.8	36.2	17.3
33. Creation of "Dolly" sheep	17.7	31.0	34.3	17.0

5. A high percentage of students (79.6%) identified six main genetics topics as difficult to understand (Figure 3).

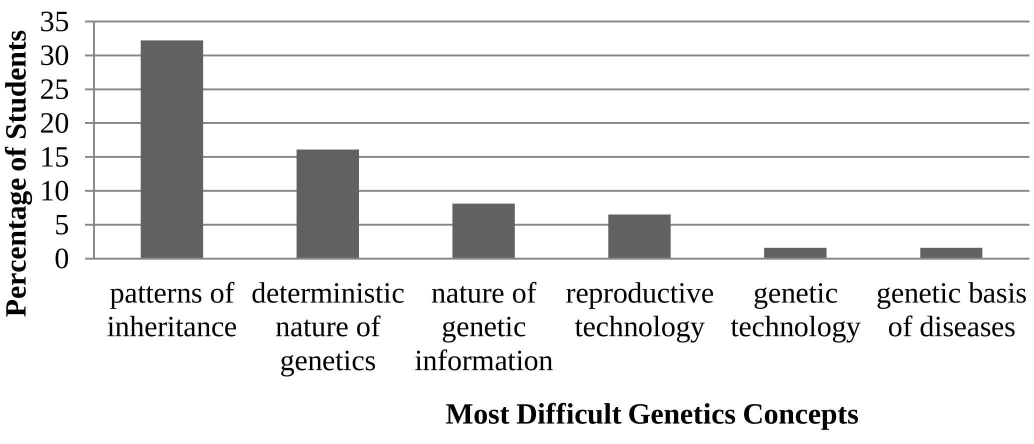


***Figure 3*. Percentage of students identifying difficult genetics concepts in decreasing order of difficulty.**

6. Findings depicted more or less the same misconceptions and difficulties in genetics, especially in the meiotic and genetics models, among students in public and private schools.
7. Students across all grade levels revealed a low level of genetics literacy (63.8-90.9%) and failed to correctly explain genetically-related world phenomena (69.8-89.6%) (Table 4).

Table 4.

Percentages of Responses for the Benefits of Cloning (Item 36A) by Grade Level

Grade	Cures Diseases (%)	Making new organs and tissues (%)	Avoiding animal extinction (%)	Increase species population (%)	I don't know (%)
7	2.2	1.5	1.5	1.5	93.3
8	0.0	0.0	0.0	0.7	99.3
9	21.1	0.0	0.9	4.4	73.7
10	8.0	3.6	2.9	1.5	83.9
11	8.2	6.0	6.0	2.2	77.6
12	17.2	19.0	5.2	1.7	56.9

8. Students attributed their difficulty in understanding genetics to (a) the national biology textbook which lacks coherence, logical sequencing, meaningful illustrations, and activities that meet their cognitive levels and (b) the use of traditional teaching methods.
9. Students attributed their misconceptions to erroneous ideas accumulated from previous instruction/informal sources, mostly evident in responses of G7-8 students.
10. Student recommended strategies to overcome learning difficulties and increase genetics literacy, including: re-sequencing concepts, introducing genetics at early grade levels, using multi-media to explain abstract processes (e.g. meiosis, protein synthesis…), and adopting student-centered teaching that promotes deeper understanding.

DISCUSSION & CONCLUSIONS

Similar to their peers of other nationalities, G7-12 students in Lebanon showed high levels of misconceptions and exhibited difficulties in understanding basic genetics concepts. Possible reasons include abstractness, cognitive demand of complex concepts, erroneous ideas acquired from informal sources, and the lack of prior-knowledge essential for understanding new and more advanced genetics concepts.

Similar to previous research (e.g. Haambokoma, 2007), findings indicate that the nature of misconceptions and difficulties originate from external factors (curriculum content, teaching methodology…), and not from students. Moreover, the low level of students' genetics literacy probably stems from overlooking social and ethical issues in student textbooks and/or during instruction.

Analysis of students' responses to OMC items showed that many students chose the correct answer that reflects a high level of conceptual understanding by selecting longer phrases, guessing, or seeking teachers' assistance. Consequently, the reliability of research using OMCs in determining the level of conceptual understanding is questioned. Alternative reliable tools might include open-ended questions and interviews.

Implications for practice underscore the importance of teachers' and curriculum developers' awareness of students' misconceptions, difficulties, and level of development, to ensure effective instruction and ultimately enhance understanding. Additionally, this study highlights some measurement practices that researchers need to consider when selecting the most reliable tools for assessing the evolution in the level of student understanding of core concepts in any scientific domain.

REFERENCES

Castéra, J., Clément, P., Abrougui, M., Nisiforou, O., Turcinaviciene, J., Sarapuu, T., … Carvalho, G. (2008). Genetic determinism in school textbooks: A comparative study conducted among sixteen countries. *Science Education International, 19*(2), 163-184.

Donovan, J., & Venville, G. J. (2014). Blood and Bones: The influence of the Mass Media on Australian Primary Children's Understanding of Genes and DNA. *Science & Education, 23*(2), 325–360.

Duncan, R. G., & Reiser, B. J. (2007). Reasoning across ontologically distinct levels: Students' understandings of molecular genetics. *Journal of Research in Science Teaching*, *44*(7), 938-959.

Duncan, R. G., Rogat, A., & Yarden, A. (2009).A learning progression for deepening students' understandings of modern genetics across the 5th-10th grades. *Journal of Research in Science Teaching*, *46*(6), 655-674.

Haambokoma, C. (2007). Nature and causes of learning difficulties in genetics at high school level in Zambia. *Journal of International Development and Cooperation, 13*(1), 1-9.

Hadenfeldt, C. J., Bernholt, S., Liu, X., Neumann, K., & Parchmann, I. (2013). Using Ordered Multiple-Choice Items To Assess Students' Understanding of the Structure and Composition of Matter. *Journal of Chemical Education, 90*(12), 1602–1608.

Lemke, J. L. (1990). Talking science: Language, learning, and values. In J. Green (Ed.), *Language and educational processes*. Norwood, NJ: Cablex.

Lewis, J., & Kattmann, U. (2004). Traits, genes, particle and information: Re-visiting students' understandings of genetics. *International Journal of Science Education, 26*(2), 195-206.

Lewis, J., & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance- do students see any relationship? *International Journal of Science Education*, *22*(2), 177-195.

Maskiewicz, A. C., & Lineback, J. E. (2013). Misconceptions Are "So Yesterday!" *CBE—Life Sciences Education, 12*(3), 352–356.

Mills Shaw, K. R., Van Horne, K., Zhang, H., & Boughman, J. (2008). Essay contest reveals misconceptions of high school students in genetics content. *Genetics, 178*(3), 1157-1168.

Roseman, J., Caldwell, A., Gogos, A., & Kurth, L. (2006). Mapping a coherent learning progression for the molecular basis of heredity. *Paper presented at the National Association for Research in Science Teaching Annual Meeting.* San Francisco, CA.

STUDENTS´ MISCONCEPTIONS ABOUT INVISIBLE RADIATION

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Abstract: For good science teaching it is necessary to possess knowledge about students' preconceptions. A lot of studies about typical ideas that students bring to the science classroom have been conducted in science education research. Most of these studies focus on mechanics, optics and thermodynamics, whereas only a few of them deal with electromagnetic radiation (e.g. Rego and Peralta, 2006 or Neumann and Hopf, 2012). The present case study aims at exploring ideas and preconceptions of 17-year old students on the topic of invisible radiation. Over a one-year-period those students did a small research work for their final exam. They worked on different topics in the field of radiation (e.g. UV or IR). During this one-year-period semi-structured interviews with the students were conducted and written drafts of their reports were collected. In spring 2015 the final interviews, the student's research documents and videos of their final presentation were conducted. The analysis involves open and axial coding additionally to constant comparative methods from Grounded Theory. First findings show that the interviewed students possess a sophisticated conception about the danger of radiation. They have problems to define the concept of artificial. Students differentiate between artificial and natural radiation, but they are not able to distinguish between these concepts. Furthermore, an evidence-based mental model of the sender-receiver-concept could be developed.

Keywords: radiation; students´ conceptions; case study; mental model

INTRODUCTION

In the last decades of educational research a lot of research in the field of student misconceptions has been carried out. There are plenty of conceptions for mechanics, optics or thermodynamic documented (Driver, Guesne, & Tiberghien, 1985; Duit, 2009; Müller, Wodzinski, & Hopf, 2011). It is interesting, that there is only little research in the field of invisible electromagnetic radiation (Neumann & Hopf, 2012; Rego & Peralta, 2006). The results are pointing out different misconceptions for electromagnetic radiation. Due to their design these documented conceptions were hints for further investigations. For every modern technology (WIFI, Microwave, Mobile phones…) electromagnetic radiation is an important part. Therefore students should have a good understanding of the scientific concepts of radiation.

There are three goals in this project. The first goal is to find and describe misconceptions of students about electromagnetic radiation. One question is, whether the misconceptions are similar to the one found in Neumann and Hopf (2012) and if they are, can they be described in a better way. The second goal is to understand the learning processes of the students through their research. What do they learn? Do they change their conceptions about radiation? The third goal is to investigate, if there is a conceptual change (Duit, Treagust, & Widodo, 2008) observable. In which way can the change be observed? What sort of problems can be witnessed? The presented results focus on the first goal of the study.

METHOD

The study is designed as case study. A group of seven students (aged between 17 and 18) from four different schools in Vienna volunteered to work with the author for more than a year. These students conduct a small study about the conceptions of younger pupils about radiation. These studies were designed as empirical studies with interviews or questionnaires.

This research task was part of their final exam. They had to write an additional report at the end and made a presentation about their results.

Before the students began to work on their study, a semi-structured interview took place. There were several questions about the perceptions of radiation to create different associations with the term “electromagnetic radiation”. These associations were grouped to a mind-map and the students explained why they arranged it in their own particular way. Additional to that the students where asked about their knowledge about X-rays, ultraviolet radiation, infrared radiation and microwaves.

These interviews were coded and analysed with methods from Grounded Theory (Strauss, Corbin, Niewiarra, & others, 1996) (open coding; axial coding; constant comparison) to get well-described categories for the perceptions of the students. The produced mind maps were another big part in the data analyses process. Due to the explanations of the students we were able to enrich the information that lies in these maps. We can understand the structure and also the concepts that control the ordering process. The maps were compared to a scientific order of the terms brought up by the students. This scientific order was made by the author and discussed with experts in science education and practicing teachers to validate the “right” map.

During their research the students where supervised and continuously advised (for example: how to conduct the research, how to analyse the date and so on) by the author and their teachers. They used different methods to investigate the conceptions of the younger pupils and tried to work in a scientific way. We first thought about using the data collected by the students for further analyses. Though it is a problem to use the data they collected. Students are not scientists so their data is flawed in many ways, from bad interview questions to questionnaires that are not well constructed. Nevertheless every student wrote a final report and presented the results at the end in a fifteen-minute presentation. These presentations were filmed. Afterwards, a post- interview with questions similar to the first one was conducted with every student.

Through the whole year of the study an enormous amount of data was collected and not every piece of data is analysed yet. We can therefore give only a small glimpse of the results we expect after analysing the whole data set. In the next section, first results referring to the interviews and the first written documents from the students will be presented.

RESULTS

Mind maps

In figure 1 and 2 two different examples of mind maps are printed. Figure 1 shows a map with a clear physic-based structure. The student refers in the interview to the electromagnetic spectrum. His scheme is the spectrum and the different types of radiation are ordered on this spectrum with several additional terms.

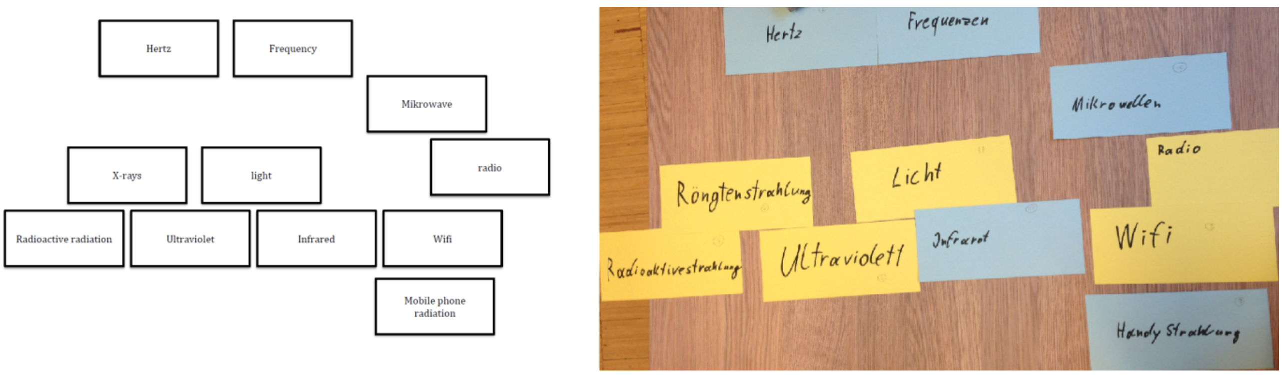

Figure 1. Mindmap from Student 1

The map of figure 2 is quite different. The structure is not clear in a scientific view. The student refers in the interview to some semantic links he made between the associations. Most of his explanations were ad-hoc constructions in the interview. He had no overall system in his mind map. What we can identify are different islands. Various terms on one island fit together in his explanation. Overall we found a great variety of maps. Most of them were not in a physical based order. Therefore we can conclude, that even after eight years of science education, only a little percentage of students is capable of making a systematically right order from a physics point of view.

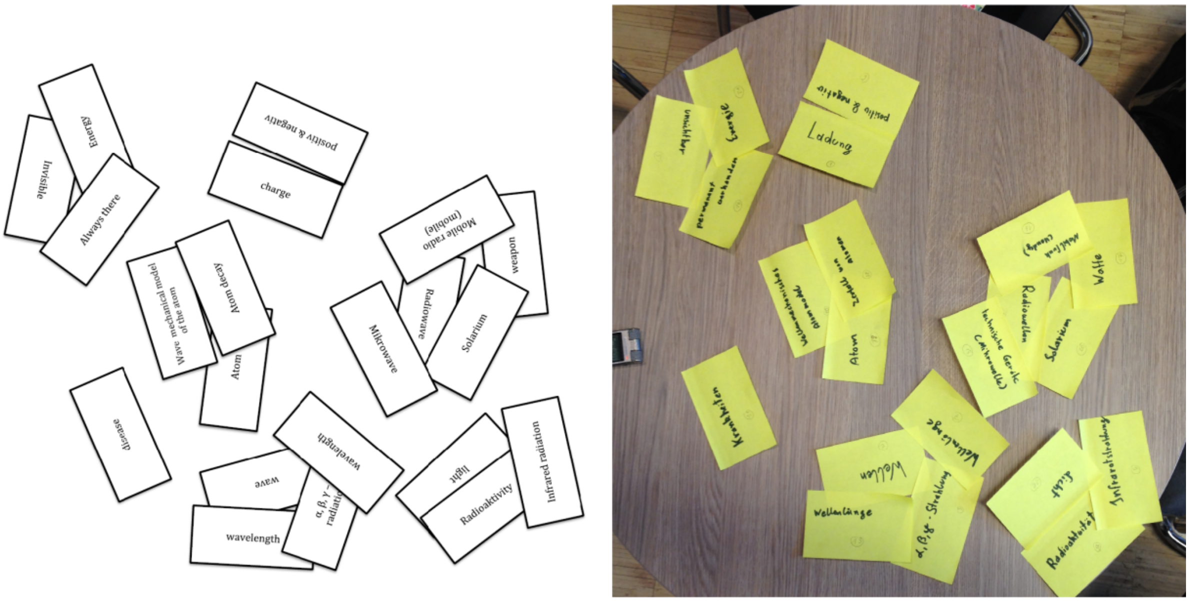

Figure 2. Mindmap from Student 2

Mental model

Two models were found in the interviews and the following drafts. The first refers to the understanding of the sender-receiver-concept. Two students claim, that if they turn of the WIFI on their mobile phone, there will be significantly less radiation around them. They do not understand that some devices are only changing electromagnetic radiation into a form, which is perceivable for the human body (see Figure 3). Turning off the changer won´t affect the source and therefore won´t reduce the amount of radiation. So there is confusion between sender, changer and receiver. In this model the changer can be any machine transforming electromagnetic radiation into a perceivable

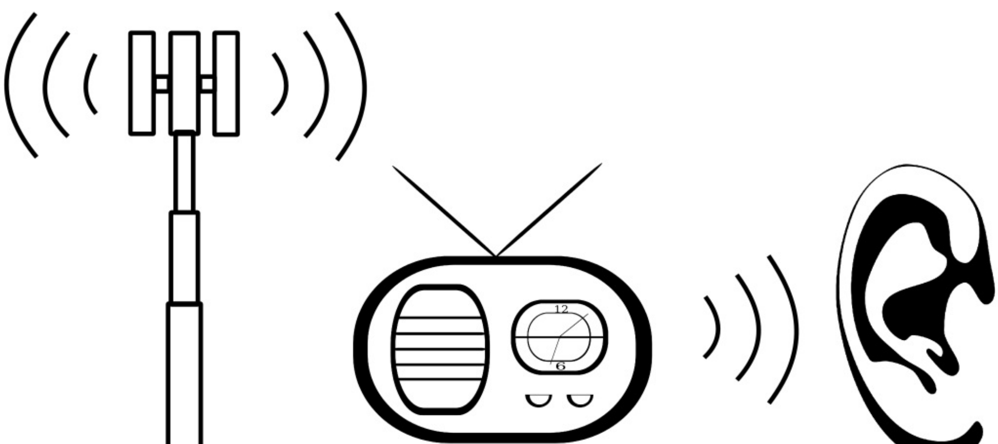

Figure 3. Model „sender-changer-receiver“

form. As an example we can take a radio (changing radio waves into sound) or an infrared camera (changing infrared-radiation into a visible picture). Looking closer to this model, we examine that a lot of problems refer to this concept. Knowing the difference between a changer and a source is necessary to understand the concepts of radiation. Most parts of the spectrum are not perceivable for the human body and so we have to use changers to detect those parts. Confusing those changers with the source leads to false conclusions.

The second model refers to the understanding of the danger of X-rays. The effect of X-rays for the body is not clear for the students. There is evidence in the data, for relaying on a sort of a threshold value for damage caused by radiation. Is the amount of radiation below this value, the students claim that there is no health-risk. Damage is only caused, if the threshold value is passed over. The human body has a certain resistance to radiation. There is a threshold that defines the dose of radiation that can be handled by the human body without damage (see Figure 4). In radiology this model has been vigorously debated in the last years. Nevertheless the linear model is widely used in the explanation of the relation between low radiation dose and cancer.

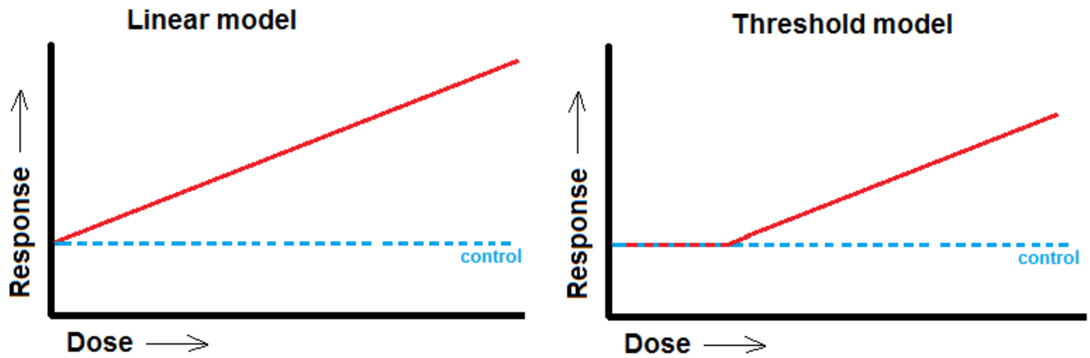

Figure 4. Two models of human response to radiation

Additionally, one student argues using the quote from Paracelsus “All things are poisons, for there is nothing without poisonous qualities. It is only the dose which makes a thing poison.” (Paracelsus & Pörksen, 2003) talking about dose and response.

> “I mean, the dose makes the poison, clearly,…[1]” student 5

She argues that ultraviolet radiation is much more dangerous than radiation from wireless LAN. She also point out, that the X-rays are dangerous but useful and if you don´t have an X-ray very often it does not matter at all.

Radiation is artificial

Students struggle with this point. They do not realize that electromagnetic radiation is always around us and every object emits radiation. So they name radiation as artificial. They also argue that machines like a microwave oven or a mobile phone produce radiation. This type of radiation is classified as artificial. On the other hand, they talk about the sun, which they name a natural source of radiation. There emerges a conflict between the concept of natural and artificial. This conflict is non-detachable for the students during the interview. They are not able to define attributes to decide whether something is natural or artificial.

DISCUSSION AND CONCLUSIONS

The results above lead to some interesting conclusions.

First, there are a lot of new concepts in the field of radiation, which are not documented previously: The mind maps lead to the assumption, that the knowledge is not structured and shows a big diversity. That leads to the conclusion, that students were not empowered to understand basic structures in the field of radiation. This fact is surprising because the students are at the end of their physics education in school and invisible radiation is part of the curriculum in Austria. Further studies should investigate this problem to find more evidence for the conclusion above. Maybe a change in the curriculum is a solution to this problem. Today radiation is not a single point in the curriculum like mechanics. Different types of radiation appear on different points in the physics curriculum. A summery and holistic view to the topic is therefore not guaranteed.

Second it is surprising, that the students have better understanding about the danger of radiation in general. The result from Neumann and Hopf (2012) that “radiation is dangerous” can not be completely confirmed for the students in this study. There is a great variation in the answers from the students relating to the danger of radiation. X-rays for example are seen as useful in the context of medical use, but also identified to cause cancer. The threshold model refers to a confusion of dose and amount of radiation. We are not able to explain this confusion yet.

Third and last conclusion refers to the problem of differing artificial and natural. The question if radiation is artificial or natural is not important in the world of physics; thus, it may be concluded the result is worthless from a professional physicist point of view. Keeping however in mind that students constantly struggle with this question we can conclude that teaching radiation, as a topic should avoid this problem. Often the students tie negative feelings to the adjective artificial. So when teachers introduce radiation in the context of technical things, radiation can be tied to this negative feeling. Teachers assume the topic is interesting for students when it is linked to their everyday life. This focus on technology probably leads to the problem of understanding. We suggest introducing radiation as a natural phenomenon and addressing therefore the positive thoughts that are tied to the adjective natural.

Electromagnetic radiation surrounds us. This key idea is hard to believe for most of the students. The source-changer-receiver-model is a reference to this idea and the misleading conclusions. We have to develop teaching concepts and material to address this idea and help students understand this basic principle.

It must be mentioned, that there are clear limitations of this study. The predictions and models above cannot be generalized due to the design as a case study. Notwithstanding, the results are a hint to further investigations.

Overall the study shows that the misconceptions found by Neumann and Hopf seem to develop with age. This opens the field for further investigations. The results above are hints to understand the possible structure of the misconceptions. Future findings may help to classify their structure relating them to the different existing theories (a great overview is given in Aufschnaiter & Rogge, 2015).

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[1] Translations from German by the first author.

REFERENCES

Aufschnaiter, C. von, & Rogge, C. (2015). Conceptual Change in Learning. In R. Gunstone (Ed.), *Encyclopedia of Science Education* (pp. 209–218). Dordrecht, Heidelberg, New Yorl, London: Springer Netherlands.

Driver, R., Guesne, E., & Tiberghien, A. (1985). Children's ideas and the learning of science. *Children's ideas in science,* 1–9.

Duit, R. (2009). *Students' and Teachers' Conceptions and Science Education*. Retrieved from http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html

Duit, R., Treagust, D. F., & Widodo, A. (2008). Teaching science for conceptual change: Theory and practice. *International handbook of research on conceptual change,* 629–646.

Müller, R., Wodzinski, R., & Hopf, M. (Eds.). (2011). *Schülervorstellungen in der Physik: Festschrift für Hartmut Wiesner* (3. unveränd. Aufl). Köln: Aulis-Verl. Deubner.

Neumann, S., & Hopf, M. (2012). Students' Conceptions About 'Radiation': Results from an Explorative Interview Study of 9th Grade Students. *Journal of Science Education and Technology, 21*(6), 826–834.

Paracelsus, & Pörksen, G. (2003). *Septem defensiones: Die Selbstverteidigung eines Aussenseiters*. Basel: Schwabe & Co.

Rego, F., & Peralta, L. (2006). Portuguese students' knowledge of radiation physics. *Physics Education, 41*(3), 259–262.

Strauss, A. L., Corbin, J., Niewiarra, S., & others. (1996). *Grounded theory: Grundlagen qualitativer Sozialforschung*: Beltz, Psychologie Verlags Union Weinheim.

PROMOTING TRANSFER CAPABILITY OF SECONDARY STUDENTS THROUGH CONTEXT-BASED EDUCATION

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Abstract: Context-based education has been stated as a valid approach for improving the learning of science but still needs to be clarified how to effectively handle this methodology to learn key ideas of the theories of science. Meaningful learning has been characterized as transfer capability (i.e. applying science knowledge in new contexts) and four groups of 15-year-old secondary students have been investigated. The different results have been interpreted and correlations between teaching strategies and transfer have been identified. The focus of the scientific literacy to be transferred has been the competency "Explain and predict phenomena scientifically" and the science content was the particulate nature of matter. Data was collected using questionnaires for students (for transfer assessment) and interviews with their teachers (to identify their educational aims and methods for introducing and assessing).Additional data was collected about the willingness and reasons of students to continue or not with scientific or technologic studies. The results show significant better transfer results for two of the groups, one of them had a high socio-cultural background and they were used to high demanding assignments while the other one had a low socio-economic status but a wide range of fruitful teaching strategies were used, namely metacognitive regulations, school science activity (which means learning content through real experimentation) and context-based teaching of concepts. The amount of students that are willing to pursue a scientific itinerary was additional data. A new framework for transfer in science education is discussed to relate the several aspects involved and to characterize the transfer profiles of students. The proposed scheme may be useful for the design of scientific literacy assignments as well as for the elaboration of context-based teaching-learning sequences that might help all types of students to be scientifically literate.

Keywords: Transfer, context-based, secondary school

INTRODUCTION

Lack of relevance and difficulty for transfer knowledge are two of the major problems that science education has to face in the third millennia (Gilbert et al. 2011). Context-based education has been regarded in many researches as a valid approach for increasing the interest in science, which may result in an increase of vocations in science and technology (Ultay and Calik 2012). Nevertheless, more research is needed to clarify the effect of the use of contexts in learning key ideas of the theoretical models of science that are considered as essential in a "Science for all" curriculum (Broman and Parchmann, 2014). For this reason, contextualizing cannot only mean that students learn descriptive information of the relevant situations but it has also to include the learning of theoretical models that are useful for all citizens.

In a previous research (Marchán-Carvajal and Sanmartí, 2013), a proposal of criteria for the design of context-based teaching-learning sequences that may foster transfer capability was validated through a case study. The analysis of the data showed us the potential of contexts when they are used as a guiding thread that articulates a wide range of teaching strategies, among which metacognitive regulation activities must be highlighted for its contribution to meaningful learning. It seems reasonable to carry out another research that seeks for a more general validation of this approach in comparison to other conventional methodologies. Therefore, the specific objectives of the research are as follows:

1. To analyze the transfer capability of several groups of students, one of them with a context-based approach.

2. To identify effects on transfer capability related to teachers' pedagogical content knowledge (PCK).

3. To interpret and describe transfer capability of students and their difficulties.

METHODS

This research was carried out in four high schools of the region of Barcelona, Spain. All of them were State Schools in urban areas but there were significant differences in students' typology (see table 1). We used a total sample of 158 students mostly aged 14 or 15 years old. They are in year 9 of compulsory secondary education and it is the last year that science is compulsory.

Table 1. Comparison of schools

High School	Number of students	Socioeconomic background of students	Number of students with special needs
A	48	Low	High
B	40	Medium-low	Medium
C	33	High	Low
D	37	Low	High

This is a mixed methods research. On the one hand it is a quasi-experimental research because group D of students has followed a context-based approach to learn key ideas of chemistry along the school year and as a result it will be considered as an experimental group while groups A,B and C were control groups. On the other hand transfer performance is interpreted according to the information gathered from an inductive analysis of students' answers to a questionnaire and interviews to their teachers. The questionnaire consisted of six questions that required applying key ideas of the particulate nature of matter in different relevant and meaningful contexts, i.e. transferring. A 40-50 minutes semi-structured interview to the science teacher of each group was carried out to characterise their PCK. Finally, the willingness of the students to choose the optional subject "physics and chemistry" the next year as well as the reasons for doing it (or not) were treated as additional data.

An inductive analysis of the answers to the questionnaire was done to distinguish between different levels of transfer performance of students. Five levels were identified and described according to a description from Sevian & Talanquer (2014). Table 2 shows the average level for each student, each question and each group was determined and compared using a Xi-square statistical test. As far as the interviews are concerned, five aspects of teacher's comments in the interviews have been highlighted for having a possible effect (fostering or hindering) on the transfer performance of their students. See table 3 for a description of each aspect and how it may affect transfer performance, according to the theoretical frameworks from the literature. Lastly, students of each group were classified in three groups: those that want to choose physics and chemistry next year, those that do not want and other. The main reasons given by students for their future intentions were qualitatively analysed and four categories were found: intrinsic motivation (I), extrinsic motivation (E), perception of self-efficacy (P) and other reasons (O).

Table 2. Levels of performance in transfer assessed from the mode of reasoning

Level	Mode of reasoning	Description
0	Prestructural	None of the necessary ideas of the model are cited in the answer.
1	Unistructural simple	Only one aspect of the necessary ideas of the model is cited and a relation with the problematic context is not established.
2a	Unistructural relational	Only one aspect of the necessary ideas of the model is cited but a clear relation with the problematic context is reasoned.
2b	Multistructural simple	Several aspects of the necessary ideas of the model are cited but a relation with the problematic context is not established.
3	Multistructural relational	All the necessary ideas of the model are cited and a full answer with clear relations to the context is provided.

Table 3. Teachers PCK components and how they contribute to transfer

Aspect of teaching	Description	Fosters transfers when...
Model-based inquiry (Windschitl. et al, 2008)	Integrating laboratory experiments with science theories for learning specific concepts through the interpretation of the results	Taking profit of active engagement to meaningfully learn science theories. Engagement with experiments and manipulating substances and instruments.
Scientific literacy assessment (Fensham 2009)	Assessment of the application of science knowledge in contextualized activities	Get used to be assessed in a non-memoristic way. Not just repeating a classroom exercise but facing a new problem that can be solved when related to what has

		been learnt in lessons.
Metacognitive regulation	Self and peer-to-peer assessment, sharing learning goals, sharing assessment standards to check them periodically, activities of "what has been learnt so far".	Student's interaction helps in learning and also self-reflection about what is known and not, and what to do to solve the difficulties that appear.
Contextualisation (Gilbert 2006)	Use of the context as the guiding thread of the sequence when learning the key ideas	Engagement with the context makes important the need to learn new concepts to understand a situation or solve a problem.
Key ideas and theoretical models (Harrison & Treagust 2000)	Selection of key ideas of the theoretical models and establishing relationships between them.	Learning abstract ideas of science (and how they are related) that are universal is important for transferring from one situation to another.

RESULTS

The average level of transfer performance for each group (table 4) and for each question (table 5) was done according to the rubric described earlier (table 2). Students from groups C and D have a significant difference (p-value lower than 0.05) in their ability to apply key ideas of the particulate nature of matter in several contexts.

Table 4. Average level of transfer performance for each group

High school	Group average of the test
A	0,6
B	0,8
C	1,4
D	1,4

Table 5. Average level of transfer performance for each question

Question	1	2	3	4	5	6
A	0,8	0,5	1,0	0,5	0,1	0,7
B	1,0	0,6	1,1	1,1	0,4	0,7
C	1,9	1,8	1,6	1,3	0,7	1,2
D	1,6	0,9	2,0	2,1	1,3	0,9

A qualitative description of the five elements that contribute to transfer for each teacher has been done from their appearance in the transcription of the interviews. Table 6 shows the percentage of students of each group that has the intention to choose the optional subject physics and chemistry next year. Table 7 shows the percentage of each category of reasons.

Table 6. Percentage of students that want to chose Physics and chemistry next year

High school	% yes	% no
A	42	46
B	15	83
C	39	55
D	65	35

Table 7. Percentage of each category of reasons

School			Yes				No	
	I	P	E	O	I	P	E	O
A	35	2	6	0	12	12	17	4
B	5	2	7	2	25	45	10	2
C	21	0	18	0	6	12	33	3
D	42	10	10	0	3	16	12	4

The pedagogical content knowledge of the teachers from the sample was characterised through the interviews and the collection of their written tests. The analysis of all this content has been done using the five components of PCK from table 3 and results are shown in table 8.

Table 8. Description of the PCK components for each teacher

Teacher	Model-based inquiry	Scientific Literacy Assessment	Metacognitive Self-assessment	Contextualization	Theoretical models and abstract ideas
A	Separates Experiments and theory	Reproductive, simple and without context	Not used	Known but no used because it is too difficult	Only Ideas of science
B	Separates experiments and theory	Reproductive, simple and without context	Used as a group discussion after exams	Not known and not valued as useful	Ideas of and about science
C	Separates experiments and theory	Productive, complex, without context, Mostly calculations	Used when students explain what they do on the blackboard	Known, used in an optional subject and very prone to know more about this methodology	Ideas of and about science
D	Integrated modelling through experiments	Productive, complex and within context Mostly Explaining	Used in individual and small group activities	An integrated context-based and modelling approach is used	Ideas of and about science

DISCUSSION

As far as the relation between students' transfer capability and teachers' PCK, the previous results suggest that:

- Integrating modelling processes with inquiry experiments so that the key ideas of theoretical models are learnt meaningfully fosters that this knowledge can be transferred.

- Assessing students using contextualised, productive and complex assignments combined with the appropriate metacognitive self-assessment strategies contributes positively to transfer.

- Low social status students may obtain similar learning outcomes in transfer compared to high social status students when PCK of teachers is based on research-based evidences in science education.

- Teaching a selection of abstract science ideas does not necessarily mean that this knowledge can be transferred to real-world situations (the problem of the “Inert knowledge”, according to Bransford et al. 1986).

- Teaching experience and being a discipline specialist is not a crucial element of PCK that contributes to transfer capability of students.

As far as the relations between students' perception of the relevance of science and teachers' PCK the previous results suggest that:

- Using the context-based approach with relevant situations improves students’ perception of the relevance of science and generate interest in it.

- Using a model-based inquiry approach and metacognitive self-assessment strategies contributes to intrinsic motivation for science, it may reduce the number of students that are demotivated because they feel that science is too difficult for them.

- Other aspects such as teaching style (attitude, communication, humour...) may play a relevant role in the learning process and the perception of science relevance.

Nevertheless, more research is needed to clarify all this issues because there are many other variables that are contributing to transfer capability and motivation of students, such as the teaching style (empathy, communicative style, affiliation, among others).

CONCLUSIONS

Firstly, the significant differences in average transfer performance between the four schools may be interpreted in terms of the socio-economic status of students but school D (experimental) has a similar performance to school C despite the fact that C has a more favourable socio-cultural background and fewer students with special needs. This may indicate that the PCK of the teacher is contributing to transfer capability.

Secondly, these differences in performance can also be interpreted in terms of the educational priorities of the science teachers, as well as the teaching strategies they use. The assessment of scientific literacy using new problems that have not been treated in class (schools C and D) must have contributed to transfer capability because students are more used to apply science knowledge in unknown scenarios. In addition, students in school D were involved in self-regulation activities that must have helped them to meaningfully learn the theoretical models. Another strong point of teacher D is the integration of experiments for the construction of the theoretical model. In the other schools experiments were carried out as a separate curriculum and disconnected of the learning of science models (“theory lessons”) which makes more difficult for students to engage in the understanding of abstract entities.

Thirdly, the differences in performance in the six questions may be attributed to the difficulty of the transfer task, which has been interpreted in the literature (Gilbert et al. 2011) as the similarity (near versus far) between the learning and the final context. In order to clarify why some tasks could be called “far transfer” and other “near transfer”, a scheme of the dimensions involved when transferring science knowledge is presented in figure 1.

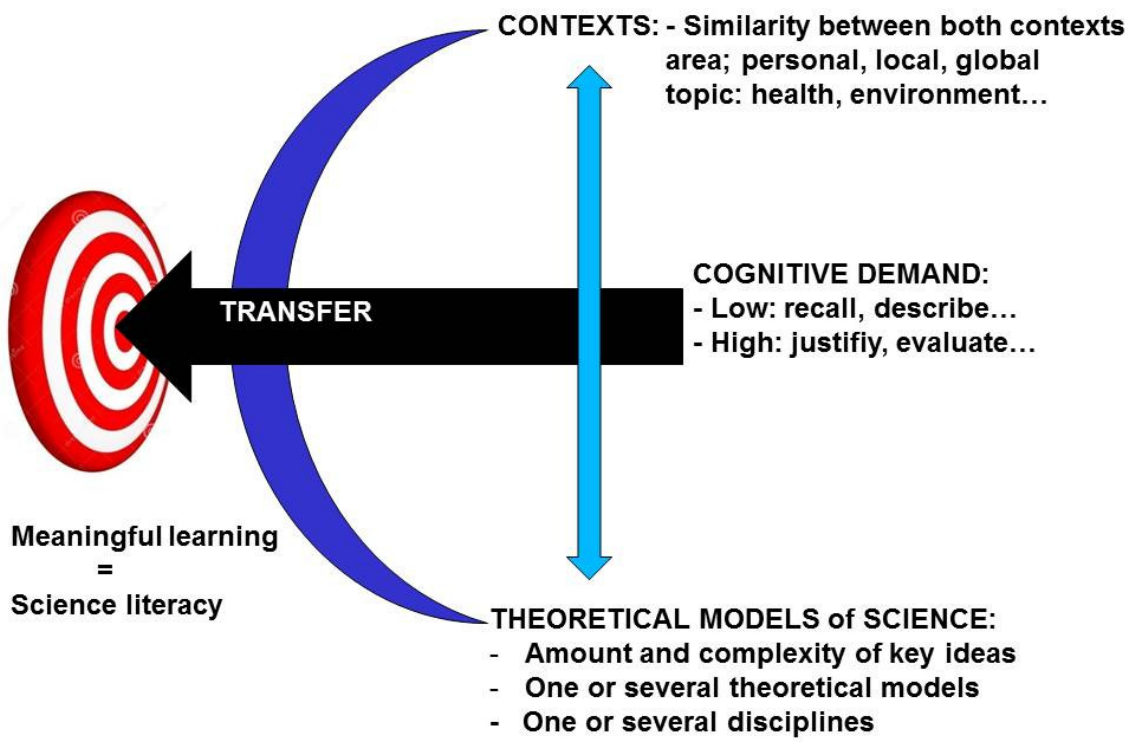

Figure 1. Scheme of the dimensions involved when a transfer has to be carried out.

Finally, the different amount of students that are willing to pursue a scientific or technological career is higher in school D may be justified by the use of relevant contexts in classroom. Making the utility of science explicit to students must contribute to student's perception of the importance of science in the real world and also in their professional future .

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REFERENCES

Broman, K., & Parchmann, I. (2014). Students' application of chemical concepts when solving chemistry problems in different contexts. *Chemical Education Research and Practice*, 15(4), 516–529.

Bransford, J., Sherwood, R., Vye, N., & Rieser, J. (1986). Teaching thinking and problem solving: Research foundations. *American Psychologist*, 41, 1078-1089.

Fensham, P. J. (2009). Real world contexts in PISA science: Implications for context-based science education. *Journal of Research in Science Teaching*, 46(8), 884-896.

Gilbert, J. K. (2006). On the Nature of Context in Chemical Education. *International Journal of Science Education*, 28(9), 957-976.

Gilbert, J. K., Bulte, A. M. W. & Pilot, A. (2011) Concept development and transfer in Context-Based science education. *International Journal of Science Education*, 33(6), 817-837.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education*, 22(9), 1011-1026.

Marchán-Carvajal, I. & Sanmartí, N. (2013), Validation of principles for the design of teaching-learning sequences that foster the transfer of learning in science education. *Paper presented at the ESERA 2013 Conference*, Nicosia, Cyprus.

Sevian, H., & Talanquer, V. (2014). Rethinking chemistry: a learning progression on chemical thinking. *Chemistry Education Research and Practice*, 15(1), 10.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, 92(5), 941-967.

Ültay, N. & Çalik, M. (2012) A thematic review of studies into the effectiveness of context-based chemistry curricula. *Journal of Science Education and Technology*, 21(6), 686-701.

"ORGANIC & ACTION" – AN EDUCATIONAL GAME TO TEACH ORGANIC CHEMISTRY

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Abstract: In this work we present an educational board game named "Organic & Action" related to some organic chemistry concepts like nomenclature, chemical structure, function and isomerism. The game was designed and implemented with secondary students (15-17 years) at a Brazilian public School in Rio de Janeiro. Our goal was to review and rework those conceptual topics with the students. The usefulness of this game as an educational tool was evaluated using a 5-point Likert-type scale. The results showed that the game "Organic & Action" was well accepted by students. The distribution of students' responses is majority "*strongly agree*" score in both perceptions about the usefulness of the game and as an educational tool. The conceptual errors of the students helped teacher to lead them to reevaluate their answer using hints or additional questions discussed with the class. The game successfully motivated students to review and rework their organic background, providing enjoyable activities in classroom and enabled socialization of the students.

Keywords: educational game, organic chemistry.

INTRODUCTION

Chemistry learning is not an easy task for most students. Its specific vocabulary, associated with the abstract concepts, interpretation of different models and mathematic skills became the teaching-learning process a real challenge for teachers and students at any level. The students should be able to deal with concepts like chemical formulae, equations, nomenclature and functions. Sirhan (2007) reported that "*the interplay between macroscopic and microscopic worlds is a source of difficulty for many chemistry learners*". But also the representational level of chemistry is a great obstacle to be overcome by students.

Regardless of abstract thought of students to be fundamental in chemistry learning, sometimes to memorize some concepts is required. For example, the set of rules to name chemicals, to write down chemical formulae or even to point out the correct organic function present in a molecule. In that case, the student's motivation is very important to reduce obstacles in the learning process and educational games can achieve this goal (Franco-Mariscal, 2014).

People can growth their knowledge dealing with the working memory, processing a few information at time (Khoii and Sharififar, 2013). The literature states that the students' achievements are related not only with memorization strategies but also with elaborations e control learning strategies (Areepattamannil and Caleon, 2015). So, the act of playing games can help the construction of students' long-term memories (Antunes *et al.*, 2012).

Educational games are a very nice tool to motivate students and to improve attention and memory of them (Franco-Mariscal *et al.*, 2015). They can be used to introduce or reinforce conceptual topics. But its powerful aspect is the playful. In spite of Daubenfeld and Zenker (2015) state that "*application of game-based learning will not automatically improve student achievement*", numerous educational games are proposal in the literature to study chemistry. For example, board game (Antunes *et al.*, 2012; Bayir, 2014), digital 3D game (Chen *et al.*, 2014) and card games (Costa, 2007; Franco-Mariscal *et al.*, 2012; Bayir, 2014; Martí-Centelles & Rubio-Magnieto, 2014; Moreno *et al.*, 2014).

In this work we present an educational board game named "Organic & Action" related to some organic chemistry concepts like nomenclature, chemical structure, function and isomerism. The game was designed and implemented with secondary students at a Brazilian public School in Rio de Janeiro. Our goal was to review and rework those conceptual topics with the students. The usefulness of this game as an educational tool was evaluated. The conceptual errors of the students helped teacher to lead them to reevaluate their answer using hints or additional questions discussed with the class.

METHOD

The educational game "Organic & Action" is based on a mixture of strategy and chance like a roll-and-move board game, where player's tokens are moved based on a throw of the dice. The game is composed by a board game (Figure 1), 5 tokens, 1 regular dice, 1 hourglass and 50 cards (Figure 2). The game requires a minimum of two teams. Figure 1 presents an english version of the board of the game.

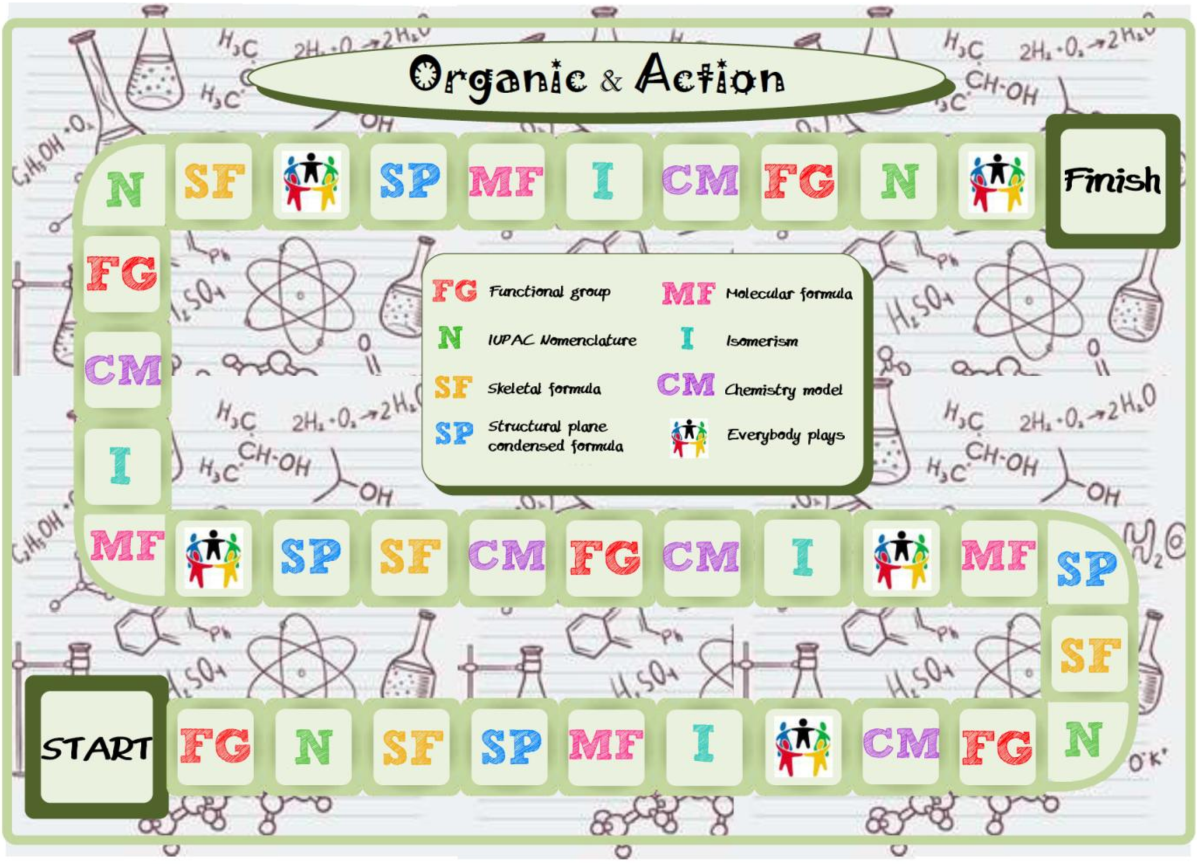

Figure 1. The English version of the board used in the game "Organic & Action". Labels: FG- *functional group*, N- *IUPAC nomenclature*, SF- *skeletal formulae*, SP- *structural plane condensed formulae*, MF- *molecular formulae*, I- *isomerism*, CM- *Chemistry model*, - *everybody plays*.

To play the game, the teams initially position their tokens on the square labeled "*Start*" (see Figure 1). First, one player of each team throws the dice to see who start the game (get the greatest number) and the sequence of players. After that, the player rolls the dice and advances the number of squares indicated on it. Each square of the game board is labeled with a letter representing a specific question (see Figure 1 and its caption). So one player of the team picks the first card out of the pile and writes down on the blackboard one of the data describe on the card – *name, structural formulae or skeleton formulae* (see Figure 2) that it should be different from the question. Then, the others players of the team have 3 minutes to give the answer. If the answer was correct the same team plays again. If it was wrong the next team rolls the dice and plays. The team that reaches the last square labeled "*Finish*" first wins. The teacher supervises the game and judges the students' answers.

Figure 2 presents a set of three cards used in the game. All cards in the game contain the IUPAC name, the structural formulae and the skeleton formulae of an organic compound. Basically, one can find some cards representing hydrocarbons (alkanes, alkenes and alkynes), alcohols, ethers, aldehydes, ketones, carboxylic acids and esters.

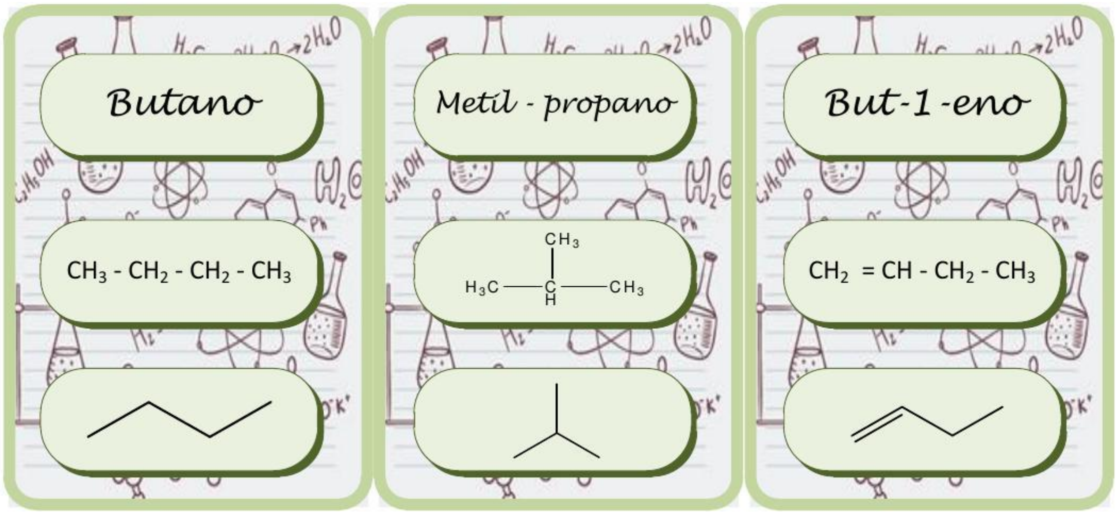

Figure 2. A set of cards used in the game "Organic & Action". The substances are *Butane* (left), *methylpropane* (center) and *but-1-ene* (right).

At the end of the game the students' perceptions of the usefulness of the game as educational tool was achieved using a survey containing 13 items (Table 1). A 5-point Likert-type scale was used from *strongly agree* (one) to *strongly disagree* (five). The students also have the *no opinion* (SO) option.

Table 1 presents the thirteen items used in the survey and its respective subjects and statements for response.

Table 1. Items used for students' perceptions.

Item	Subject	Statements for response
		about the game
S1.	Concentration	The game demands concentration
S2.	Challenge	The game is challenge
S3.	Ability	The game demands or develops some abilities
S4.	Goal	The goal of the game is obvious
S5.	Rules	The rules of the game are understandable
S6.	Presentation	The presentation of the game is appropriate
S7.	Socialization	The game enables socialization
S8.	Satisfaction	I recommend the game to others classes
		about the educational value
S9.	Approaching	The game proper approaches the chemical subjects
S10.	Goal	The educational goals of the game are obvious
S11.	Motivation	The game is motivating
S12.	Application	The game is applicable to others chemical concepts
S13.	Adaptation	The discussed content is appropriated to my skills

The game was developed in two different classes at a Brazilian public secondary school (15-17 years). Class A consisted of 22 students (7 males and 15 females) and class B 28 (7 males and 21 females), which were arranged into teams of 5-6 at the beginning of the term. The game was used to review and reinforce the subjects of nomenclature, chemical formulae, molecular geometry, function and isomerism in organic compounds.

RESULTS

Figures 3 and 4 present the graphics with the distribution of the students' responses about the usefulness of the game (items S1-S8) and as an educational tool (items S9-S13), respectively.

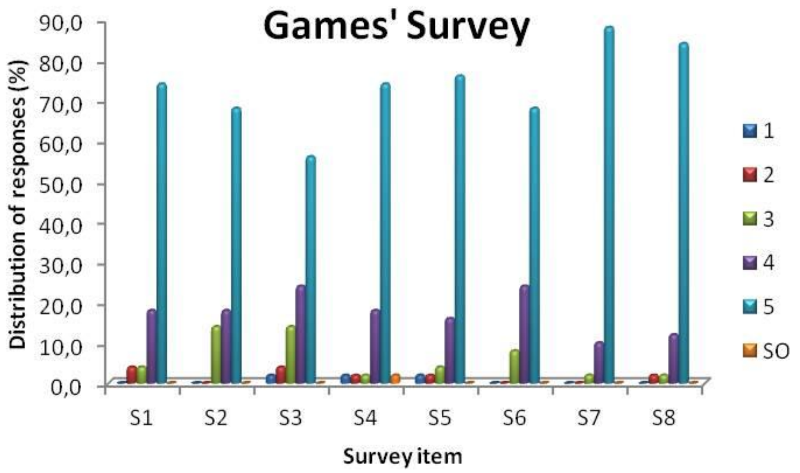

Figure 3. Survey items vs. Likert scale plot representing the students' perceptions about the "Organic & Action" game. (see Table 1)

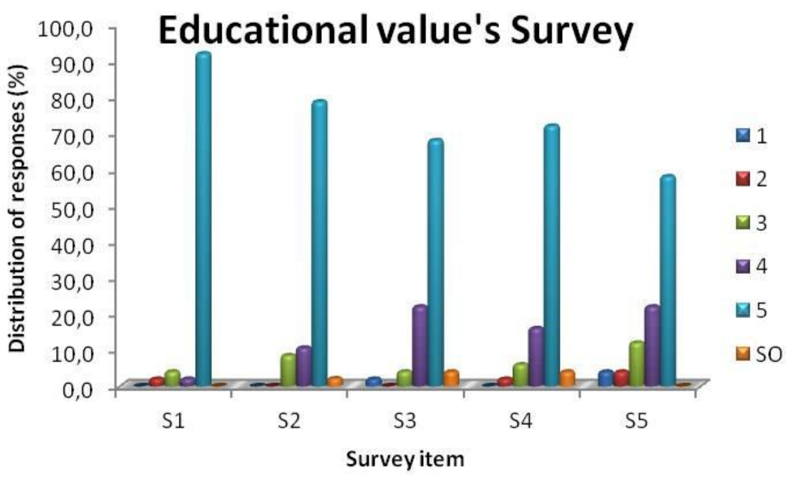

Figure 4. Survey items vs. Likert scale plot representing the students' perceptions about the pedagogical value of the "Organic & Action" game. (see Table 1)

The analysis of students' responses was procedure by descriptive statistical data analysis. The mean scores and their errors for each surveys' items were determined. Table 2 presents the mean scores and standard errors from the student's perceptions about the "Organic & Action" game. The statements for students' responses are described in Table 1. The 5 points Likert scale scoring used are: *strongly disagree* (1), *disagree* (2), *neutral* (3), *agree* (4) and *strongly agree* (5). A "*no opinion*" point was used in the survey aiming to give the students an abstention option. Nevertheless, everybody answered all questions.

Table 2. Items used for students' perceptions.

Item[a]	Mean scores[b,c]	Standard errors[c]
S1	4,62	0,11
S2	4,54	0,10
S3	4,28	0,14
S4	4,63	0,12
S5	4,62	0,12
S6	4,60	0,09
S7	4,86	0,06
S8	4,78	0,08
S9	4,84	0,08
S10	4,72	0,09
S11	4,60	0,11
S12	4,65	0,10
S13	4,26	0,15

[a]See Table 1 for the survey statement text.
[b]Mean scores on a 1-5 Likert scale scoring as *strongly disagree* (1), *disagree* (2), *neutral* (3), *agree* (4) and *strongly agree* (5).
[c]$N = 50$.

DISCUSSION AND CONCLUSIONS

The analysis of data suggested that the game "Organic & Action" was well accepted by students. The distribution of students' responses (see Figures 3 and 4) is majority "*strongly agree*" score in both perceptions about the usefulness of the game (items S1-S8) and the educational tool (items S9-S13). These results are reaffirmed by the average values from Table 2. For all items the mean scores were greater than 4.5 excepted items S.3 (ability) and S.13 (adaptation). The highest rankings were S.7 (Socialization) and S.9 (Approaching) demonstrating that the game enables the socialization of students and the proper approaching of the chemical concepts discussed in the activities.

The most important point achieved was the opportunity created by the game for teacher's perceptions about the misconceptions of the students. The teacher was able to discuss about those conceptions with the class during the game and solved them.

The game "Organic & Action" successfully motivated students to review and rework their organic background. The conceptual errors of the students helped teacher to lead them to reevaluate their answer using hints or additional questions discussed with the class. The game provided enjoyable activities in classroom and enabled socialization of the students.

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REFERENCES

Antunes, M., Pacheco, M.A.R., & Giovalena, M. (2012). Design and Implementation of an Educational Game for Teaching Chemistry in Higher Education. *Journal of Chemical Education*, 89, 517-521.

Areepattamannil, S. & , Caloen, I. S. (2015). Relationships of Cognitive and Metacognitive Learning Strategies to Mathematics Achievement in Four High-Performing East Asian Education Systems. *The Journal of Genetic Psychology*, 174(6), 696-702.

Bayir, E. (2014). Developing and Playing Chemistry Games To Learn about Elements, Compounds, and the Periodic Table: Elemental Periodica, Compoundica, and Groupica. *Journal of Chemical Education*, 91, 531-535.

Chen, M., Wong, Y. & Wang, L. (2014). Effects of type of exploratory strategy and prior knowledge on middle school students' learning of chemical formulas from a 3D role-playing game. *Educational Technology Research and Development*, 63, 163-185.

Costa, M.J. (2007). CARBOHYDECK: A Card Game To Teach the Stereochemistry of Carbohydrates. *Journal of Chemical Education*, 84(6), 977-978.

Daubenfeld, T., & Zenker, D. (2015). A Game-Based Approach to an Entire Physical Chemistry Course. *Journal of Chemical Education*, 92(2), 269-277.

Franco- Mariscal, A.J., Olivia-Martínez, J.M., & Gil, A. (2015). Students' Perceptions about the Use of Educational Games as a Tool for Teaching the Periodic Table of Elements at the High School Level. *Journal of Chemical Education*, 92(2), 278-285.

Franco- Mariscal, A.J., Olivia-Martínez, J.M., & Márquez, S.B. (2012). An Educational Card Game for Learning Families of Chemical Elements. *Journal of Chemical Education*, 89, 1044-1046.

Franco-Mariscal, A.J. (2014). How CanWe Teach the Chemical Elements to Make the Memorization Task More Enjoyable? *Foundations of Science*, 19, 185-188.

Khoii, R. & Sharififar, S. (2013). Memorization versus semantic mapping in L2 vocabulary acquisition. *ELT Journal*, 67(2), 199-209.

Martí-Centelles, V., & Rubio-Magnieto, S.B. (2014). ChemMend: A Card Game To Introduce and Explore the Periodic Table while Engaging Students' Interest. *Journal of Chemical Education*, 91, 868-871.

Moreno, L.F., Hincapié, G., & Alzate, M.V. (2014). Cheminoes: A Didactic Game To Learn Chemical Relationships between Valence, Atomic Number, and Symbol. *Journal of Chemical Education*, 91, 872-875.

Sirhan, G. (2007). Learning Difficulties in Chemistry: An Overview. *Turkish Science Education*, 4(2), 2-20.

ASSESSMENT ON JUNIOR SECONDARY SCHOOL STUDENTS' LEARNING PROGRESSION OF CHEMICAL CHANGE

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Abstract: For the development of students' progressive and deep understanding of chemistry big idea, the study aims to evaluate students' progressions of chemical change to know: students' learning progression and how to improve teaching according to the results of the assessment. We built a hypothetical learning progression of chemical change by unpacking the big idea-chemical change into smaller constructs represented by a concept map on the inspection of chemistry standard, university chemistry textbooks, junior secondary school chemistry textbooks; and the development of assessment tasks. All the concept maps and propositional knowledge statement and 15 tasks developed were validated by a college expert who was involved in teaching chemistry, a junior secondary school chemistry teacher, a college expert who was involved in teaching chemistry education. Then we developed the instrument which used to make empirical progressions. About 211 students were involved in the large scale paper and pencil test. Six teachers participated in the interview to help students' building progressions and concluding the results. Six chemistry educators finished the work of scoring. Scorer reliability was calculated by SPSS program. And the program was used to calculate the frequencies, ANOVA and *T* test. Rasch model were used to (1) review if certain items were necessary to add or delete; (2) divide different progression levels. From the study, we can see that: there were 3 progressions from 'knowing', 'applying' to 'problem solving'; students' learning progressions of chemical change were not quite consistent with which were expected; the 1st level of 'knowing' progressed significantly, while other abilities in 'problem solving' level, such as reflection and evaluation, inferring, designing, generalizing and putting forward new questions are expected to be improved. Instruction is essential for students' progressions and teachers' understanding of core concepts is very important.
Keywords: assessment, learning progression, chemical change

INTRODUCTION

Over the past decade, there has been increased interest in learning progression(LP) (Smith , Wiser, Anderson , Krajcik ,2006; Salinas ,2009).Recent studies focused on curriculum design(National Research Council[NRC],2012),instruction and assessment(Xiufeng Liu&Kathleen,2005; Wilson 2005,2009; Johnson&Tymms, 2011).Four building block model(Wilson 2005,2009) and construct-centered design(CDD) process (Shin,Stevens,Short & Krajcik,2009) has been followed to build learning progression. Rasch's measurement model has been used more and more to divide different learning progressions (Xiufeng Liu, 2010) in specific domain.

Students' heavy academic burden in junior secondary school has been a real problem of Chinese education; it has also been mentioned to solve in the next 10 years. Through decades of implementation of chemistry curriculum, we have seen far from meeting the demand of the problem-solving, because there is too much detail to be memorized. Therefore, it is necessary to assess students' progressive and deep understanding of big ideas, such as chemical change. However, large-scale examination, as well as homework , to assess the students' deep understanding is weak.For the development of students' progressive and deep understanding of chemistry big idea, the study aims to evaluate students' progressions of chemical change. It is important to know: What is the junior secondary students' learning progression of chemical change? Whether instructions influence students' progression and how to improve present teaching.

METHOD

There is lots of definition of learning progression. From the perspective of curriculum study, to develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months. Findings from research about children's learning and development can be used to map learning progressions in science. That is, one can describe the successively more sophisticated ways of thinking about a topic that can follow and build on one another as children learn about and investigate a topic over a broad span of time (e.g., 6 to 8 years) (NRC, 2007).Learning progressions may extend all the way from preschool to 12th grade and beyond-indeed, people can continue learning about scientific core ideas their entire lives (NRC, 2012).

From the perspective of instruction, learning progression is descriptions of successively more sophisticated ways of thinking about an idea that follow one another as students learn: they lay out in words and example what it means to move toward more expert understanding (Smith et al., 2006).

From the perspective of assessment and evaluation, learning progressions are descriptions of successively more sophisticated ways of thinking about an idea that follow one another as students learn: they lay out in words and examples what it means to move toward more expert understanding. Learning progressions should be developed around the organizing principles of science such as evolution and kinetic molecular theory. Such organizing principles-which are sometimes referred to as the big ideas of science-are the coherent foundation for the concepts, theories, principles, and explanatory schemes for phenomena in discipline （NRC,2005）.

Synthesized different definitions of learning progression, it is regarded that: learning progression raised concerns about the curriculum, instruction, assessment and paid a lot of attention to students. From the perspective of the development of individual and group of students, learning progressions describes the start, process and end of learning, with time as the 'scale' to measure students' development and define learning content. In this study, we considered more on junior secondary students' progression in one year.

Previous studies of learning progression focused on two facets in chemistry: key concepts and inquiry learning skills. Some research focused on the nature of matter, for example, atomic structure, electrical force (Stevens, Delgado& Krajcik, 2010); others studied macroscopic properties of matter, atomic-molecular explanations of matter and so on (Johnson&Tymns, 2011); still others research on the growth over academic year in understanding matter (Xiufeng Liu, 2005, 2006).Previous researches seem to paid little attention to chemical change. While, in this study, we focus on the big idea 'chemical change', for it is the most important learning content and main object in chemistry. We refer to 'change' because in junior secondary school students are taught to distinguish between physical changes and chemical reactions/chemical changes.

Rasch's measurement model is widely used to develop the assessment of learning progression.

It is an item response theory (IRT), which tries to get an objective and equally spaced scale through testing students' reaction. Recently, Rasch's measurement model has been used more and more in psychology and pedagogy for it overcame the CTT's (Classical Test Theory) disadvantages of tool-dependent and sample-dependent. Previous studies developed 'four building blocks' to test students' learning progressions, which include: (1)construct maps; (2)the items design; (3)the outcome space; (4)evidence of high-quality assessment(Wilson,2005,2009). Science educators proposed construct-centered design process (Shin et al., 2009), and computer model based-assessment (Xiufeng Liu, 2010) process. Based on the literatures, we followed the steps: (1) Build the model of specific domain cognitive mode by interview, content analysis and mental simulation for cognitive activity; (2) Unpacking and constructing the framework; (3) Constructing learning progressions assessment; (4) Develop instrument based on Rasch's measurement model;(5) Survey and revise the cognitive mode and instrument;(6) Identify the level of learning progressions-build the level model; (7) Use the level model to find the difference among students; (8) Use the level model to trace students' progression.
The process can be divided into 2 parts. First, researchers need to unpack the core idea into smaller ones which serves as a Hypothetical Learning Progression (HLP). Second, by data collection and analysis students' performance, researchers built development level model. This step include review on misconceptions and students interview; then design items, conduct pilot test and build the 'scaling rule' according to students' performance. Questionnaire survey then followed, to get the evidence of students' performance. Data analysis is based on Rasch's measurement model from which to revise the items and characterize the development level.

Build a Hypothetical Learning Progression (HLP)

Similar to construct-centered design process, we unpacked the big idea –chemical change into smaller construct in a concept map based on inspection of chemistry syllabus. As a reliability check, in order to ensure all the knowledge referred to the same topic area, seven concept maps were developed. The entire concept maps were validated by a college expert who was involved in teaching chemistry, a junior secondary school chemistry teacher, a college expert who was involved in teaching chemistry education. **Tasks**, such as recognizing, predicting, were chosen based on Bloom's taxonomy of Educational Objectives (Revised), and informed by the analysis of the large scale assessment, such as PISA, TIMSS, NAEP, and the inspection of the national standards documents.

Table 1. Task and performance in items

Task	Performance
Produce/Generalize	Put forward new questions
Reflect /Evaluate	Reflect/evaluate experimental design effectively
Conclude	Prove/Argue/Find Solutions; Draw Conclusions
Design	Design experimental procedures, or select and effectively combine experimental apparatuses
Hypothesize/Predict	Predict based on given information
Infer	Infer from one or more perspectives
Analyze	Analyze certain types of chemical reactions from one or more perspectives
Explain	Explain types of chemical changes
Judge/Decide	Make judgments on types of chemical changes
Compare/Contrast	Compare two or more types of chemical reactions
Summarize/Classify	Determine the type of chemical reaction
Translate	Interpret chemical reaction information from tables or figures
Exemplify	Cite required examples
Represent	Represent/Describe the phenomena of chemical changes
Recognize	Remember the knowledge related to change. e.g., Write familiar chemical reaction equations

After inspection of experts, we developed the HLPs of students' performance aiding by Winstep3.72.0 software (John M. Linacre, 2011) and SPSS SPSS17.0 statistical software.

Developing Empirical progressions (EP)

Instrument

Multiple-choice items and constructed-response items were designed to examine whether the students were able to accomplish certain tasks.

Participants

About 211 students form 3 junior secondary schools were involved in the research. Six teachers from the 3 junior secondary schools accepted the interview.

Data analysis

The data were analyzed by the score. Six chemistry educators finished the work of scoring. Scorer reliability was calculated by SPSS program. And the program was used to calculate the frequencies, ANOVA and *T* test. Winstep as a software based on Rasch's measurement model was used to (1) review if certain items were necessary to add or delete; (2) divide different progression levels.

RESULTS

Analysis of the performance test data provides results regarding the students' progressions. As described earlier, we used the Rasch's measurement model to develop the measuring instrument. After revising the items, we finally selected 60 items to make the item pool to test the students' performance. In total, 211 students participated in the test. As for reliability, participant reliability was 0.90, while item reliability was 0.98 .Next, we checked the validity by person-item map (see Figure 1). From Figure 1, we can conclude that, on the whole, the items developed matched the students' abilities.

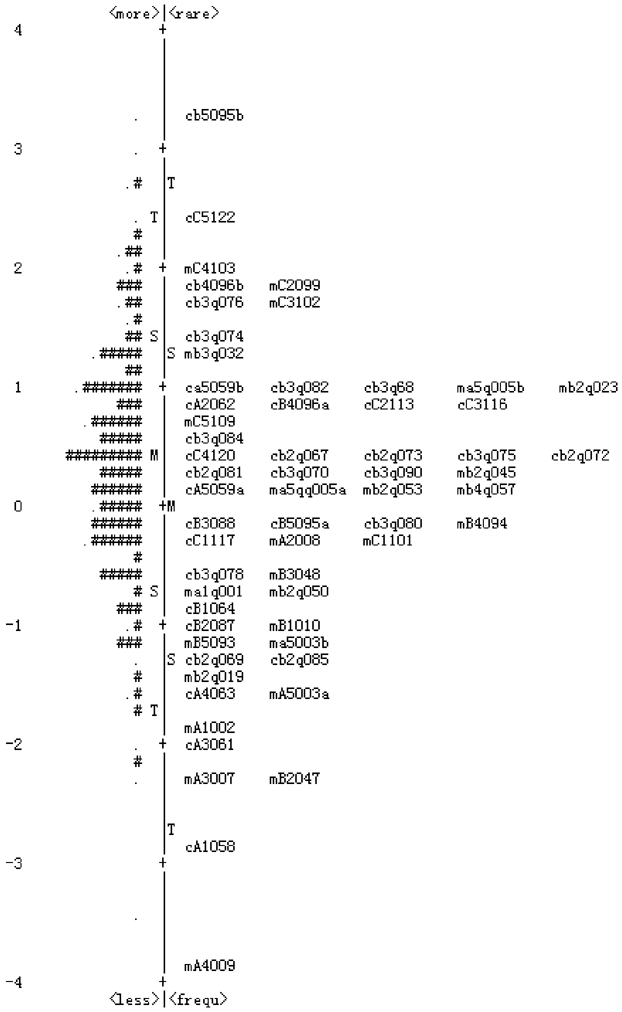

Figure 1. Person-item map of students' performance

However, there is a problem with these results: we were unable to compare differences among students with respect to their progress as repeated items. To solve this issue, we selected 15 items for the main concept of 'change' to create a level model. Each item belongs to a certain task, as shown in Table 1, such as remembering or analyzing, etc.

First, we used Winstep3.72.0 software to make the person-item map of the students' performance with respect to the concepts of 'chemical change' (see Figure2).

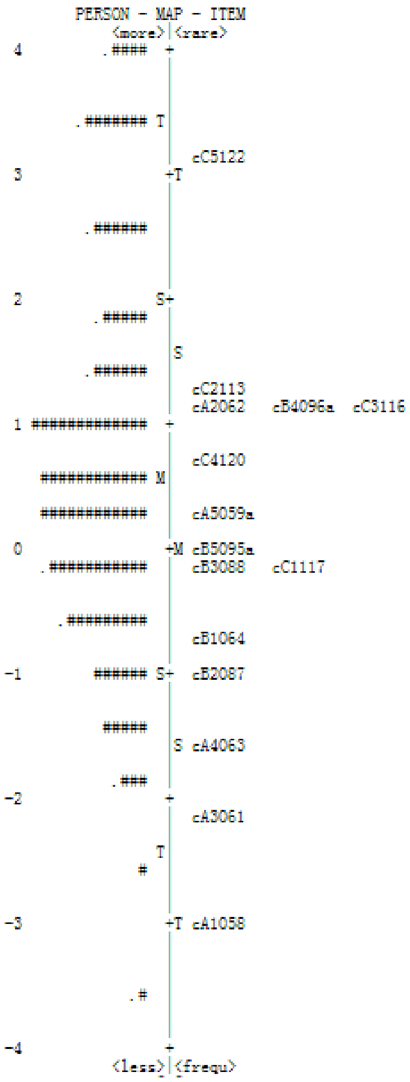

Figure 2. Person-item map of students' performance for 'chemical change'

For the results shown in Figures2, we used SPSS 17.0 software to make a paired- sample *T* test for level division (see Tables 2).

Table 2. Paired-sample *T* test for 'chemical change'

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	cA1058– cA3061	.057	.303	.021	.016	.098	2.724	210	.007
Pair 2	cA3061–cA4063	.057	.333	.023	.012	.102	2.479	210	.014
Pair 3	cA4063–cB2087	.066	.473	.033	.002	.131	2.036	210	.043
Pair 4	cB2087–cB1064	.033	.581	.040	-.046	.112	.830	210	.407
Pair 5	cB2087–cB3088	.142	.389	.027	.089	.195	5.313	210	.000
Pair 6	cB3088–cB5095a	.009	.647	.045	-.078	.097	.213	210	.832
Pair 7	cB3088–cA5059a	.062	.704	.048	-.034	.157	1.271	210	.205
Pair 8	cB3088–cC4120	.137	.565	.039	.061	.214	3.534	210	.001
Pair 9	cC4120–cC3116	.076	.564	.039	.000	.152	1.953	210	.052
Pair 10	cC4120–cB4096a	.085	.619	.043	.001	.169	2.002	210	.047
Pair 11	cC4120–cA2062	.085	.678	.047	-.007	.177	1.828	210	.069
Pair12	cC4120–cC2113	.090	.558	.038	.014	.166	2.346	210	.020
Pair13	cC2113–cC5122	.232	.515	.035	.162	.302	6.555	210	.000

Note: $P < .05$

According to the data above, students' performance for 'chemical change' can be divided into eight levels, in three hierarchies (Table 3).

Table 3. Levels of junior secondary students' performance for 'chemical change'

Hierarchy	Level	Item	Description of Level
H3: problem solving	L8	cC5122	Produce/Generalize
	L7	cC2113	Design
	L6	cA2062，cB4096a，cC3116，cC4120	Represent, Analyze, Conclude, Reflect/Evaluate
H2: applying	L5	cA5059a，cB5095a，cB3088c,C1117	Summarize/Classify, Infer, Explain, Hypothesize/Predict
	L4	cB1064，cB2087	Compare/Contrast, Judge/Decide
H1: knowing	L3	cA4063	Translate
	L2	cA3061	Exemplify
	L1	cA1058	Recognize

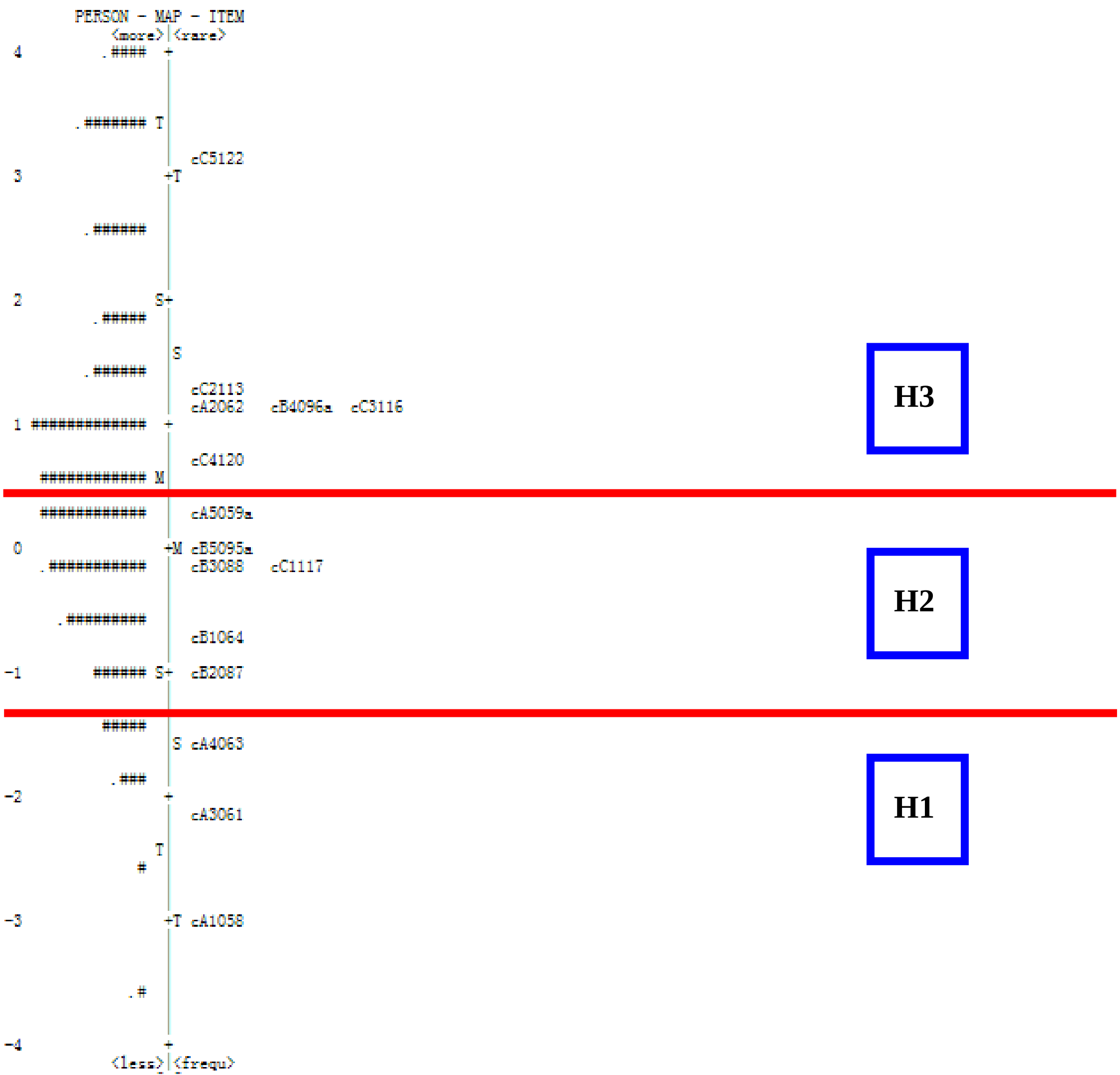

Figure 3. Hierarchies of students' performance for 'chemical change'

Thus, we can assess the students' performance in chemistry from the stage of knowledge acquisition to problem solving. The level model for the concepts of 'chemical change' can be used as a scale to test the different performance levels of students from different schools to make pedagogical suggestions for each school, and to measure students' progression from grade 1 (G1) to grade 2 (G2). Grade 1 and grade 2 students were assessed to see their progress. The grade 1 means that students were tested after acquiring new knowledge. The grade 2 means that students were tested after they had finished their junior secondary school chemistry learning and passed the senior secondary school entrance exams. The results are shown in the following tables (Tables 4) and figures (Figures 4 to 5).

From Table 4 we can see the frequencies of students' right answers for 'chemical change.' While it was expected that the grade 2 student would show better performance for 'chemical change' because of their more experienced levels of learning, not all of the actual performance results did fit this expectation.

Table 4. Student performance by grade for 'chemical change'

Hierarchy	Level	Item	Description of Level	G1/%	G2/%	Total/%
H3: problem solving	L8	cC5122	Produce/Generalize	30.0	10.0	20.0
	L7	cC2113	Design	60.0	58.3	59.2
	L6	cC3116	Conclude	38.3	73.3	55.8
		cB4096a	Analyze	38.3	43.3	40.8
		cA2062	Represent	55.0	85.0	70.0
		cC4120	Reflect/Evaluate	53.3	48.3	50.8
H2: applying	L5	cA5059a	Summarize/Classify	96.7	100.0	98.3
		cB5095a	Infer	63.3	61.7	62.5
		cC1117	Hypothesize/Predict	45.0	93.3	69.2
		cB3088	Explain	36.7	43.3	40.0
	L4	cB1064	Compare/Contrast	60.0	83.3	71.7
		cB2087	Judge/Decide	70.0	90.0	80.0
H1: knowing	L3	cA4063	Translate	66.7	95.0	80.8
	L2	cA3061	Exemplify	81.7	98.3	90.0
	L1	cA1058	Recognize	91.7	100.0	95.8

Data analysis by *T* test showed that student performance was significantly different for the items of 'recognize (p=.002, <.05)' , 'exemplify(p=.000, <.05)' , 'represent(p=.000, <.05)' , 'translate(p=.000, <.05)' , 'judge(p=.001, <.05)' , 'compare/contrast(p=.000, <.05)' , 'predict(p=.000, <.05)' , 'conclude(p=.000, <.05)' and 'produce(p=.001, <.05),' for 'chemical change.' All the performance scores for the grade 2 group were better than those of the grade 1 students, except for the item of 'produce/generalize' (see table 4) .The students in these groups seem to have not been taught to put forward new questions for 'chemical change.'

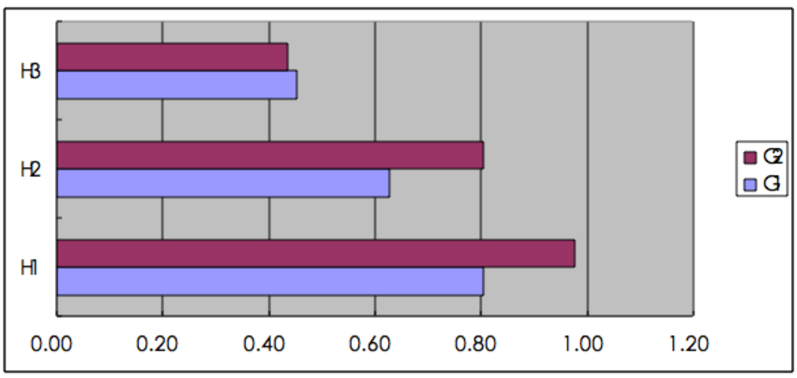

Figure 4. Student performance hierarchies for 'change' (from G1 to G2)

From Figure 4, for Hierarchy 3, the students in grade 2 did not perform better than the students in grade 1.

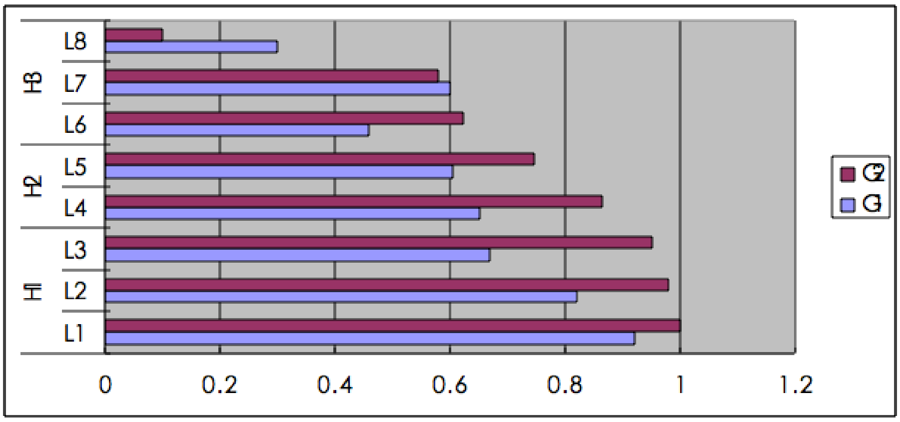

Figure 5. Student performance levels for 'change' (from G1 to G2)

From Figure 5, for levels 8 and 7, students in grade 2 did not perform better than those in grade 1. We can see progress at the lower levels and middle levels, but not at the higher levels. Some abilities, such as putting forward new questions, seemed to be neglected in the classroom.

DISCUSSION AND CONCLUSIONS

There are different progressions in chemical change which are not quite consistent with the expected. It has been found that:

Students' learning on chemical change was divided into 3 learning progressions form 'knowing', 'applying' to 'problem solving'. Knowing is the first progression level. It is easier for students to memorize familiar chemical change and write down chemical equations; classify the type of chemical reactions. To compare or explain is more difficult. It is hard for students to design experiment procedures, or select and effectively combine experiment apparatus, or prove/argument/ find solutions/draw conclusions. Reflection/evaluation effectively on experiment design is difficult task to finish.

Students' learning on chemical change progressed in the 1-year junior secondary chemistry instruction, especially in 'knowing' level. Obviously, we can see student' progression of recognizing, exemplifying, translating, judging and comparing. But, some abilities are expected to be improved, such as the ability of 'explain'. Additionally, students' ability on predicting and concluding after recitation are better than that of new teaching. Some abilities progression is weak, for example, explaining, analyzing and classifying. Reflection and evaluation, inferring, designing, generalizing and putting forward new questions are expected to be improved.

Problem solving is the most difficult hierarchy of students' progression. Some of the tasks in this hierarchy had not progressed significantly after recitation instruction, such as generalizing and putting forward new questions .We should reflect whether students had been asked to finish this kind of task in our classroom. Other abilities like reflection and evaluation, inferring, designing are to be improved. Present instruction has developed students' abilities in 'knowing' level and some abilities in 'applying' and little in 'problem solving'. It is hard for students to evaluate or design because these kinds of abilities need more synthesis, or say integration, which include the synthesis of knowledge and the synthesis of knowledge and difficult tasks, such as inferring. The latter one is students' another difficulty. It is hard for students to finish difficult tasks. Thus, instruction should pay more attention of students' difficulties and present various tasks in students' activities in chemistry classroom rather than recall or recognize only. And, teachers' understanding of core concepts is very important to accomplish the above instructions.

REFERENCES

Johnson, P., Tymms, P. (2011).The emergence of a learning progression in middle school chemistry. *Journal of Research in Science Teaching*, *48*(8): 849-877.

Louise, M.T., Grady, J.V., Harrison, A.G. & Treagust, D.F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom. *Science Education*, *81*(4):387-402.

Salinas, I. (2009) Learning Progressions in Science Education: Two Approaches for Development. Paper Presented at The Learning Progressions in Science *(LeapS) Conference*. Iowa City. IA.

Smith, C., Wiser, M., Anderson, C. W, Krajcik, J.S. (2006). Implication of research on children's learning for standards and assessment: a proposed learning progression for matter and atomic molecular theory. *Measurement: Interdisciplinary Research and Perspectives*, *4*(1-2):1-98.

Stevens, S.Y., Ce ́sar Delgado, Krajcik ,J.S. (2010). Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching*, *47*(6): 687-715.

Shin,N., Stevens, S.Y., Short., Krajcik,J.S.(2009).Learning progressions to support coherence curricula in instructional material, instruction, and assessment design. Learning Progressions in Science. *(LeaPS) Conference*, Iowa City, IA.

Xiufeng Liu&Kathleen,M. (2005). Students' progression of understanding the matter concept from elementary to high school. *Science Education*, *89*(3): 433-450.

XiuFeng Liu& Kathleen, M. (2006). Progression in children's understanding of the matter concept from elementary to high school [J]. *Journal of Research in Science Teaching*, *43*(3): 320-347.

Xiufeng Liu. (2010). *Using and developing measurement instruments in science education: A Rasch modeling approach.* Charlotte, NC: Information Age Publishing.

National Research Council. (2005). *System for State Assessment*. Washington，DC: The National Academies Press．

National Research Council. (2007). *Taking science go school: Learning and teaching science in grade K-8*. Washington，DC: The National Academies Press．

National Research Council(2012)． *A Framework for K－12 Science Education: Practices，Crosscutting Concepts，and Core Ideas*． Washington，D． C． The National Academies Press．

Wilson, M.R. (2005).*Constructing measures: An item response modeling approach*. Mahwah,NJ:Lawrene Erlbaum Associates.

Wilson, M. R. (2009).Measuring progressions: Assessment Structures Underlying a Learning Progression.*Journal of Research in Science Teaching*, 46(6):716-730.

TEACHER'S MODELS ABOUT MIXING COLOURS IN NAHUATL-SPEAKING COMMUNITIES: DEPENDENCE OR INDEPENDENCE OF THE INDIGENOUS CULTURE?

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Abstract: This paper shows the development and structure of indigenous teachers' ideas about mixing colours and their ideas about colours derived from their school context and cultural traditions. In order to know the teachers' scientific school knowledge, two questionnaires and one interview were implemented. In addition, group sessions were conducted in which teachers' traditional tales and stories that were related with colours were noted. The obtained information within the present study shows a difference between the teachers' physical phenomenological ideas about colours and their cultural beliefs. Analysis of the teachers' physical phenomenological models constructions were made based on the Possible Partial Model, which states that the inferences and explanations used to describe a subject consist of constricting ideas, rules of correspondence and a set of phenomenological inferences about processes. Based on the Possible Partial Model's components, models to describe the conceptions about mixing colours were developed. The performed cultural analysis involves the way in which colours are related to their cultural environment by taking stories and tales that add properties to colours depending on their effects on people. In the scholarly context, the results showed that teachers change from a conception that focuses on colours as unchanging entities that become an additional property of the object (model M1) to the idea that colour represents a quality of substances or objects that can be modified by mixing colours (model M2). Before the intervention process, teachers implemented both models; however, after the intervention, teachers demonstrate a tendency to use model M2. It seems that there is no influence from colour's cultural aspect (colour strength or influence on people) over the teachers' constructions. Based on the results, the present study considers that indigenous culture has scarce influence over the understanding of some school physical knowledge.

Keywords: Science Education, Teacher Ideas, Models, Indigenous Education

INTRODUCTION

Several researches have been developed within indigenous communities. Most of the studies analyse the educational difficulties that evolve into learning deficiencies. These learning difficulties have several repercussions on indigenous community students. The cultural knowledge is viewed as threatened by the education on "western science" (Aikenhead & Elliott, 2010; Le Grange, 2007). The Culturally Relevant Approaches, or Cultural Responsive Schooling, orient most programs and research projects. One of the main problems in this approach is that teachers that are not native to the indigenous communities do not understand the native culture. Because of this, the main purpose of several academic researchers is to incorporate modified schoolbooks and activities that integrate the native cultural knowledge from the community. The understanding of the community and their culture is fundamental to achieving this goal (Atwater & Crokett, 2003; Lee, Yen & Aikenhead, 2012; Loving & de Montellano, 2003; Ninnes, 2003).

Research on science education with indigenous communities has shown that there is some difficulty integrating cultural knowledge with academic scientific knowledge (Kitchen, Hodson & Cherubini, 2011). There is a great challenge for teachers to understand school scientific concepts and apply them in their communities and classrooms. Such challenge, is based on multiple causes that involve a teacher's insufficient or lack of proper preparation affecting the cultural and scientific education. There is a present lack of support to indigenous educational programs and an unchanging preference to traditional education practices (Kitchen, Hodson & Cherubini, 2011; Ríos & Caballero, 2002). The same challenges can be observed with indigenous community native teachers.

From another view, the learning process in diverse cultural environments happens in an independent way. Cultural knowledge does not interfere with scientific knowledge and vice versa (Hong et al., 2000; Legare, Evans, et al, 2012). These studies focus on the cognitive processes and how they develop and activate in specific contexts.

Some studies (Gallegos et al, 2014; Gutiérrez & Rogoff, 2003) have shown that it is the scholarly environments that establish the independence between the scholarly education and the cultural context. Within this point of view, there are no studies on teachers that explain how their cultural knowledge is related to their understanding of scientific knowledge. Additionally, there is no information about the conceptual relationship from the teachers' native cultures and their knowledge and reading about science.

This research focuses on the conceptual construction of native indigenous teachers of scientific school knowledge, especially the mixture of colours. The main objective is to identify if these school constructions of teachers show some kind or relation with their cultural knowledge about colours.

The educational background of indigenous teachers in Mexico

Most of the teachers of indigenous schools in Mexico are bilingual; they speak their indigenous language and Spanish. They also belong to the community where they work. However, their preparation is not specialized in educating bilingual children. Most of the teachers from this community were educated in the teachers' rural schools or by several induction courses, and a very few in a university mainly their local UPN (National Pedagogical University). These courses had only the objective to provide an introduction to teaching bilingual children in order to prepare them as bilingual teachers (Salmerón & Porras, 2010) under the assumption that, because the educator knows an indigenous language and understands the community cultural background, they are able to teach (Ríos & Caballero, 2002).

Since 2004, there has been teaching specialization in intercultural and bilingual education. However, there has not been a specialized education for the teachers in the use of the languages. There is no further education in the indigenous language and handwriting. As a result, children and some teachers do not write in their maternal Nahuatl language.

The main educational backgrounds of teachers are Spanish and instruction in Mathematics, History and Geography. However, there is deficient or null education in the natural sciences and related topics (Ríos & Caballero, 2002). Leading to an educational shortage and great difficulty by children and teachers to understand science, which can be observed in the National Education Evaluations (INEE, 2007).

Based on the research of Castillo (1997), colours and their Nahuatl names are organised into five *basic* colours. The main colours are black, white, red, green and yellow. There are also other colours that are direct descendants from the *basic* colours. Those colours are blue, orange and purple, which are also derived from nature and come from the designation of the sky, orange and wild cherry (dark purple fruit) respectively. There are also some colours learned from the Spanish language; however, they were not originally from the community. There are tales and stories about the benefits or curses of colours. These tales are spread by verbal transmission. These tales and stories will be analysed in order to know their influence on the notions of teachers about the mixture of colours.

METHOD

Main Characteristics of the Community, Teachers and Subject Sample

The participants are bilingual teachers (Spanish – Nahuatl). They work as teachers in preschool and primary levels of education (indigenous multilevel program). They also belong to the community where they work. They belong to the township of Cuautempan, located at Sierra Norte of Puebla.

The subject sample consists of 27 teachers who work at preschools (6 teachers) and primary-level community schools (17 teachers) and 4 teachers that work as technical pedagogical counsellors (ATP). All the teachers are undergraduates, and the 4 ATP have a master's in education. None is a specialist in science education.

Research Design

During the training and before the teachers applied a didactical proposal in class, there were held two sessions to identify the meanings and use of colour in the teachers' cultural traditions. For registering the subject constructions about the colour mixing process from the scholarly context, there were used two questionnaires. The first one was applied before the preparation course (questionnaire QBI). Three months later, when teachers ended the application of the proposal with their students, they received the second questionnaire (questionnaire QAI). Also 9 teachers from the subject sample were interviewed.

Instruments

Questionnaire Before Intervention (QBI) is a questionnaire with 12 open questions about mixing colours, mixing process, their explanations and expected results.

Questionnaire After Intervention (QAI) is a questionnaire with 16 open questions included on the pre-test.

Interviews. The applied interviews were semi-structured (20 to 30 minutes), included the same topics of the questionnaires.

Acquiring of cultural ideas. Teacher participated in two sessions; in each one they told stories and tales they remembered.

Analysis Elements

The information obtained within this study in relation to the teachers' physical phenomenological ideas about colours and their beliefs about colours from their cultural point of view are quite different. The construction of physical phenomenological teachers' models was analysed from the Possible Partial Model (Flores y Gallegos, 1998, Gallegos et al, 2014). The Possible Partial Model proposal is a variation of the formal structure adapted to describe the inferences and explanations from non-scientist expert subjects about their representation or comprehension of phenomena. It is a constituted model formed by two main sets of concepts or conceptions. The first of them is the constricting concepts (CC), that is, the constrictions or conditions that the phenomenological elements should satisfy and the second is the rules of correspondence (RC) that is all kind of relationships between phenomenological elements, concepts and conditions. There is also an application set (A) that represents any phenomena that can be described by the sets CC or RC. Both sets (CC and RC) and set A are constituted in a unique model (M). In this particular research and with the purpose of broadening our proposal, we include the term of constricting ideas (CI) instead of constricting concepts. This allows us to analyse the corresponding teachers' ideas without restrictions and without modifying the proposal or the partial possible models structure.

The second subject involves how colours are related to their cultural environment. They are based on stories and tales that add properties to colours depending on their effects on people. We started from the consideration that diverse tales and stories, verbally expressed by the community, are an important cultural tradition with the main function of preserving ancestral knowledge (Montemayor, 1999). Therefore, the tales and stories also belong to the conceptions and notions from the community teachers. These ideas had a different structure that needs other types of analysis -in particular, non-sequential functional mechanisms as the Boyer and Ramble (2001) criteria: 1) be a pointer to a particular domain concept; 2) be expressed in an explicit way in which the intuitive reasoning is violated in a specific event; and 3) accomplish other intuitive expectations, that was applied. Because of these considerations, it is possible to consider tales and stories, specifically about colours, as analysis materials. They belong to their cultural model, being recognised, remembered and transmitted by the community. In addition, the consistent and coherent use of cultural ideas about colours will confirm that the teachers also share these ideas and can be considered cultural experts (Legare et al., 2012).

RESULTS

I. Colours within the community cultural context

From the sessions where teachers tell their stories and tales about colours in their tradition, there appear ideas as the colour belongs to objects; tales as that rainbow has negative effects over people. In all cases colour is an entity with the possibility to interact with people as show Table 1.

Table 1. Described tales from teachers from their cultural ideas about colours.

Colour identifications according to common objects	Negative effects from colour	Positive effects of colours
Colours come from nature. The lamb's wool has brown and black colours and it is used to produce covering material.	Cutting a purple flower makes you a dish breaker. Pointing out a rainbow with the finger can provoke disease on the pointing finger. If a pregnant woman looks at the rainbow, her child might be born without a finger. If a pregnant woman finds herself in a place that is being painted, her baby will be born with a stained face.	Red colour brings protection from jealous people and some diseases and also brings health. White flowers protect the spirits of dead people. Black colour cures and re-establishes the soul.

II. Colours in the School Context

Below will be shown, in a fragment from a questionnaire, how to obtain the elements *f* and RC from the teachers' models.

Case 4. Questionnaire QBI, Q#= question number, T2= teacher 2, preschool (all grades).

Q10: *Imagine that we gather together (one above the other) two filters (coloured transparent plastics), one of blue colour and another yellow. What would happen?*

T2: *Colour combinations.*

Q11: *In which colour do you think the things would look like? Why?*

T2: *Of two – colours, bicolour.*

In this case, teacher T2 answers that when the filters join they will produce a new combination of colours (RC.1); however, in the second answer, it can be observed that the result of the combination is that you can see two colours (*f.1*), which is a denial of RC.1. Resuming:

RC.1: The colours can be combined, mixed or joined.

f.1: When the two colours are combined, you can see at the end the two colours.

Table 2 shows the set of relations RC and the phenomenological appliances *f*.

Table 2. RCs relations and phenomenological expression sample of teachers.

RC	Phenomenological expressions (*f*)
RC.1 Coloured substances can be combined or be together. RC.2 Some colours are stronger than others. RC.3 The resulting colour of the mixture depends on the ratio or amount of the mixed colours.	*f.1* When two colours are combined, at the end, you can observe both colours. *f.2* When two colours are combined, at the end, you can observe only one of them. *f.3* When the colours are combined, at the end, you can observe the one that remains on top. *f.4* When the colours are combined, at the end, you can observe that the strongest is the one that predominates. *f.5* When the colours are combined, at the end, you observe the most weak or transparent. *f.6* When the colours are combined, at the end, you can observe a different colour (correct). *f.7* When the colours are mixed, at the end, you can observe a different colour (incorrect). *f.8* The colour observed is the result of the mixture of the other colours (inverse correct). *f.9* The colour observed is the result of the mix of other colours (inverse incorrect). *f.10* Different proportions of colour give different hues or intensities of the resulting colour.

For explaining teachers' cognitive constructions from the framework of the models, there is a need to establish the CIs and their causal inference relations. From all the obtained data, it can be observed that there are two main sets of applications or phenomenological explanations. One of them establishes that the combinations of colour do not produce a different colour (*f.1, f.2, f.3, f.4, f.5*). The other explanation establishes that the combination of two or more colours produce a different colour (*f.5, f.6, f.7, f.8, f.9, f.10*). From the first set, it is possible to infer that the colour conception is strongly related and attached to substances, and objects conditions that are found in their environment, creating an ideological barrier that cannot be modified, which can be expressed as *CI.1 Colours are entities that do not change*, corresponding to the first set of proposals. On the other hand, from the second set, it can be inferred that colours are only some qualities from substances or objects but not dependent on them; this provokes the idea that colour can change; *CI.2 Colours are modifiable qualities,* corresponding to the second proposal set.

The analysis results (CI's; RC's; f's) show that there are two main models: M1 explains an absence of change after colour combination; M2 explains that colour combination can produce a new colour. Table 3 show models M1 and M2 by teacher in questionnaires QBI and QAI.

Table 3. Use of models M1 and M2 by teacher (T is for teacher); M1-M2 means use both models; M1M2 means M2 is more used than M1.

Cycle	T	QBI		QAI	
	1	*f.2,f.4,f.6,f.7*	M1-M2	*f.6,f.8,f.10*	M2
	2	*f.1,f.2,f.4,f.6,f.7*	M1>M2	*f.6,f.7,f.8,f.10*	M2
	3	*f.1,f.6,f.7*	M1< M2	*f.6,f.8,f.10*	M2
	4	*f.2,f.3,f.4,f.6,f.7*	M1 >M2	*f.4,f.6,f.8*	M1<M2
Preschool	5	*f.2,f.4,f.6,f.7*	M1- M2	*f.4,f.6,f.8*	M1<M2
	6	*f.2,f.4,f.5,f.6,f.7*	M1 > M2	*f.4,f.7,f.9*	M1<M2
	7	*f.6*	M2	*f.4,f.6,f.8*	M1<M2
	8	*f.2,f.4,f.6,f.7*	M1-M2	*f.4,f.6,f.8*	M1<M2
	9	*f.4,f.6,f.7*	M1<M2	*f.6,f.8*	M2
	10	*f.4,f.6,f.7*	M1<M2	*f.6,f.8*	M2
	11	*f.2,f.4,f.7*	M1 >M2	*f.6,f.8,f.10*	M2
1	12	*f.4,f.6,f.7*	M1<M2	*f.4,f.6,f.8*	M1<M2
	13	*f.2,f.4,f.6*	M1 >M2	*f.4,f.6,f.8*	M1<M2
	14	*f.4,f.5,f.6*	M1 >M2	*f.4,f.6,f.7,f.8,f.10*	M1<M2
	15	*f.2,f.4,f.6,f.7*	M1-M2	*f.4,f.6,f.8,f.10*	M1<M2
2	16	*f.4,f.6,f.7*	M1< M2	*f.4,f.6,f.8*	M1<M2
	17	*f.6,f.7*	M2	*f.6,f.9*	M2-M2
	18	*f.2,f.4,f.6,f.7*	M1-M2	*f.6,f.8,f.10*	M2
	19	*f.2,f.4,f.6,f.7*	M1-M2	*f.6,f.7,f.8*	M2
	20	*f.2,f.4,f.5,f.6*	M1 >M2	*f.4,f.6,f.7,f.8*	M1< M2
	21	*f.3,f.4,f.5,f.6*	M1 >M2	*f.4,f.6,f.7,f.8,f.10*	M1< M2
	22	*f.2,f.4,f.6,f.7*	M1-M2	*f.6,f.7,f.8,f.10*	M2
3	23	*f.2,f.4,f.6*	M1 >M2	*f.4,f.6,f.7,f.8,f.10*	M1< M2
	24	*f.2,f.4,f.6,f.7*	M1- M2	*f.6,f.8*	M2
	25	*f.6*	M2	*f.6,f.7,f.9*	M2
ATP	26	*f.6 ,f.7*	M2	*f.4,f.6,f.7,f.8*	M1< M2
	27	*f.6,f.7*	M2	*f.6,f.8*	M2

DISCUSSIONS AND CONCLUSIONS

An element that stands out is that teachers, who were educated in teachers' schools and even in Pedagogical University, presented on their QBI the idea that colours cannot be mixed (CI.1). This is surprising, because most of the teacher formation focuses on basic education and preschool education. Both educational levels require particular attention to the understanding of colour and the development of activities with them.

As a second aspect, is the idea transformation process from the correspondent constricting ideas CI.2. From this process of transformation, the colour combination is possible, and therefore, there is a change from the use of model M1 to model M2. When the teachers change their conception of colours from M1 to M2 models, they shift from viewing colour as a concrete object to conceiving a transformative process, thereby reaching a better understanding of the physical process of colour subtraction (light absorption); this only happens on 44.4% of the subject sample (9/16 women and 5/11 men). However, almost all the sample (92.6%) uses the M2 model, even if it is in a shared way with the M1 model. This implies that for the teachers, there is an unclear difference between both conceptions; therefore, their inferences depend on specific colour mixtures.

Although teachers had no preference between M1 and M2 models before the intervention process, after the intervention, teachers demonstrate a tendency to prefer the use of the M2 model. Even though there is a difference between teachers' preference before and after the intervention, it seems that there is no apparent influence of cultural aspects (colour strength or colour influences on people) over teachers' constructions. Even the conception of colour as object is not particular to Nahuatl Culture, it appears in other cultures and in young children, therefore it is possible to explain it in terms of implicit physical conceptions.

Therefore, we consider that indigenous culture has little influence over the understanding and construction of some school physical knowledge. Nevertheless, other cultural elements related with different ontological issues, may be have some influence in other science topics.

We consider that the school process needs to strengthen both perspectives, as in the culturally responsive schooling approach, but always specifying their differences. For example, it is important that teachers from the analysed community have more references of their colour ideas and classifications. In this way, a clear recognition for their different context and their influence in daily, professional and school life will allow them to see academic knowledge as the "other point of view" and not as a knowledge substitution that replaces any other way of knowledge.

REFERENCES

Aikenhead, G., & Elliott, D. (2010). An emerging decolonizing science education in Canada. *Canadian Journal of Science, Mathematics and Technology Education, 10*, 321-338.

Atwater, M. M., & Crockett, D. (2003). A world view of pre-service teachers: Through the eyes of ethnicity and culture. In S. M. Hines (Ed.), *Multicultural science education: Theory, practice, and promise* (pp. 55-86). New York: Peter Lang.

Boyer, P., & Ramble, C. (2001). Cognitive templates for religious concepts: Cross-cultural evidence for recall of counter-intuitive representations. *Cognitive Science, 25*, 535-564.

Castillo, M.A. (1997). Términos de colores en el Náhuatl de Cuetzalan: Un enfoque etnocientífico [Colour names in Cuetzalan Nahuatl: an ethnoscientific apporach].

Dimensión Antropológica, 11. Retrieved from: http://www.dimensionantropologica.inah.gob.mx/?p=1382.

Flores, F. C. & Gallegos, C. L. (1998) Partial possible models: An approach to interpret students' physical representation. *Science Education*, 82, 15 - 29.

Gallegos-Cázares, L., Flores-Camacho, F., Calderón-Canales, E., Perrusquía-Máximo, E., & García-Rivera, B. (2014). Children's models about colours in Nahuatl-Speaking communities. *Research in Science Education*. *44*, 699-725.

Gutierrez, K., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertories of practice. *Educational Researcher, 32*, 19-25.

Hong, Y. Y., Morris, M., Chiu, C.Y., & Benet-Martínez, V. (2000). Multicultural minds: A dynamic constructivist approach to culture and cognition. *American Psychologist, 55*, 709-720.

INEE. (2007). El aprendizaje de tercero de primaria en México: Español, Matemáticas, Ciencias Naturales, Ciencias Sociales (Learning in third primary grade in Mexico: Spanish, Mathematics, Natural Science, Social Sciences). México.

Kitchen, J., Hodson, J., & Cherubini, L. (2011). Developing capacity in indigenous education: Attending to the voices of aboriginal teachers. *Action in Teacher Education*, *33*(5), 615-627. doi 10.1080/01626620.2011.627308.

Le Grange, L. (2007). Integrating western and indigenous knowledge systems: The basis for effective science education in South Africa? *International Review of Education*, *53*, 577–591.

Lee, H., Yen, Chiung-Fen., & Aikenhead, G. (2012). Indigenous elementary students' science instruction in Taiwan: Indigenous knowledge and western science. *Research in Science Education,* 42, 1183-1199. doi: 10.1007/s11165-011-9240-7

Legare, H. C., Evans, M. E., Rosengren, S. K., & Harris, L. P. (2012). The coexistence of natural and supernatural explanations across cultures and development. *Child Development, 83*(3), 779-793.

Loving, C.C., & de Montellano, B. R. O. (2003). Good versus bad culturally relevant science: avoiding the pitfalls. In S. M. Hines (Ed.), *Multicultural science education: Theory, practice and promise* (pp. 147-166). New York: Peter Lang.

Montemayor, C. (1999.) *Arte y plegarias en las lenguas indígenas de México [Art and prayers in the indigenous languages of Mexico]*. México: Fondo de Cultura Económica.

Ninnes, P. (2003). Rethinking multicultural science education: Representations, identities and text. In S. M. Hines (Ed), *Multicultural science education: Theory, practice and promise* (pp. 167-186). New York: Peter Lang.

Ríos, M., & Caballero, J. (2002). Perspectives on the teachers' formation of indigenous teachers for an intercultural teacher education in Oaxaca, México. *Action in Teacher Education*, *24*(2), 55-63. doi 10.1080/01626620.2002.10734419.

Salmerón Castro, I. F. & Porras Delgado, R. (2010). La educación indígena: fundamentos teóricos y propuestas de política pública [Indigenous education: theoretical foundations and policy proposals]. In Alberto Arnaut & Silvia Giorguli (Eds.) *Los grandes problemas de México* [The wide problems of Mexico] (pp. 509-575). México: El Colegio de México.

INVESTIGATING THE STUDENTS' LEARNING DIFFERENCES BETWEEN FREEZING AND EVAPORATION VIA MICROSCOPIC PARTICLES CONCEPTS IN TAIWAN

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Abstract: The phenomena of freezing and evaporation both involve a change in physical properties depending on the same factors, temperature and pressure. However literatures show, after formal teachings, students still had difficulties of understanding about freezing and evaporation. Therefore, this study investigated the students' conceptual development of the two phenomena with empirical survey and the correlations of students' learning between the two phenomena and microscopic particles. Accordingly, there were three questions of research: (1) what were students' conceptions of freezing and evaporation from fourth to twelfth grades? (2) what were the differences of students' learning about freezing and evaporation? (3) what were the correlations of students' learning about freezing and evaporation to microscopic particles? The participants were 832 fourth to twelfth graders in Taiwan. The instruments included Examination of Particle Nature (EPN) and Examination of Phase Transitions (EPT). EPN was used to examine students' understanding of particulate nature of ice, water and vapor and EPT was used to test students' conceptions of freezing and evaporation. Cronbach's αs were all over .80. The results showed that the students' concepts of microscopic particles stayed low percentage of correctness before eighth grade but increased sharply from ninth to tenth grade. Secondly, the students' conceptual development of freezing was earlier then evaporation. And the significant differences existed in identical matter and recoverability, but not in conservation of mass. Finally, the significant correlations of concepts of microscopic particles to the concepts of freezing and evaporation were found. In sum, it was inferred in this study that the origin of learning differences between freezing and evaporation was students' lack of microscopic particles concepts. Therefore, the authors suggested that pre-established microscopic particles concepts could be arranged in teachings and then could help students use the same principles to acquire a better understanding of freezing and evaporation.

Keywords: conceptual development, learning differences, freezing and evaporation, microscopic particle

INTRODUCTION

The concepts of microscopic particles are critical for students to understand in science learning. However, in most countries students learned these concepts in early middle school (approximately 11 to 14 years old) much later then they should (Martin et al., 2004). Moreover, empirical studies pointed out the low understanding of microscopic particles among middle school (Harrison & Treagust, 2002). In addition, phase transitions were frequently used to teach microscopic particles (Wu & Chiu, 2013b) because they were daily phenomena. Using empirical surveys, this study investigated what students learned about freezing and evaporation and how the concepts of microscopic particles in students' understanding of freezing and evaporation evolved.

In science education, learning processes of scientific knowledge played a major role in researches and teachings (Posner et al., 1982), i.e. Ontological tree (Chi, 2005) and Framework Theory (Vosniadou, 2002). According to researches on phase transitions, four kinds of misconceptions in phase transitions were discussed to literature review:“compositions” (Benson et al., 1993), “properties” (Johnson & Papageorgiou, 2010), “structure of three states” (Stavy, 1990; Tsai, 1999), and “transition processes” (Costu, et al., 2010). The above misconceptions involved students’ misunderstanding of microscopic particles and they often misunderstood particle motion as a direct process rather than an emergent process as shown in Chi (2005).

To sum up, this study investigated the students’ conceptual development of freezing and evaporation and the correlations to microscopic particles concepts. Accordingly, there were three questions in this research: (1) What were students’ conceptions of freezing and evaporation from fourth to twelfth grades? (2) What were the differences of students’ learning about freezing and evaporation? (3) What were the correlations of students’ learning about freezing and evaporation to microscopic particles?

METHOD

832 Taiwanese fourth to twelfth graders participated in this study, and Examination of Particle Nature (EPN) and Examination of Phase Transitions (EPT) were used to survey students. EPN was used to exanimate students’ understanding of particulate nature of ice, water and vapor. In EPN, students were to choose the properties tendency in five-level items design. EPT was used to test students’ understand of phase transitions, freezing and evaporation. Two-tier design was conducted in EPT, which the first tier items include four or five choices and the second is the reasons. According to Wu & Chiu (2013b), the internal reliabilities of EPN and EPT (Cronbach’s α) were all over .80l.

RESULTS

1. The results of EPN

In EPN, students compared the amount, mass and volume of particles in the states of ice, water and vapor. There states were different but they shared the equal amount, mass and volume of particles. Therefore, students who answered “less” properties (1 and 2) and “more” properties (4 and 5) were excluded from analysis. The numbers and percentages of correct answers (3) were shown in Table 1 and Figure 1.

Table 1. The correct numbers and percentages in amount, mass and volume of microscopic particles

Grade Concepts	4	5	6	7	8	9	10	11	12
amount of particles	2(2%)	7(8%)	5(5%)	7(6%)	19(24%)	24(26%)	60(62%)	54(56%)	52(56%)
mass of particles	1(1%)	6(7%)	2(2%)	6(6%)	14(18%)	22(24%)	54(56%)	54(56%)	49(53%)
volume of particles	1(1%)	5(6%)	5(5%)	6(6%)	13(18%)	17(18%)	36(37%)	33(34%)	36(39%)
Total in each grade	86	84	95	109	80	92	97	96	93

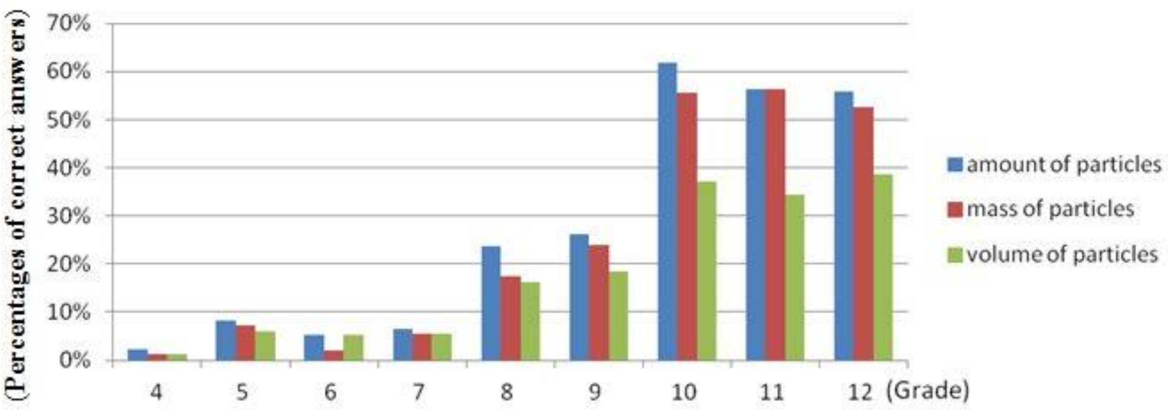

Figure 1. The bar chart of percentages in amount, mass and volume of microscopic particles

As shown in Figure 1, in tenth to twelfth grade, the percentage of correct responses increased sharply and remained over 50% for the concepts of amount and mass of particles.

2. The results of EPT

In EPT, students compared some properties of phase transitions with two phenomena of freezing and evaporation. Three properties were analyzed in this paper, including (1) Identical matter": matter is identical after transitioning, (2) Recoverability: matter can recover after transitioning, and (3) Conservation of mass: mass remains during transitioning. In freezing, the numbers and percentages of correct answers were shown in Table 2 and Figure 2.

Table 2. Count and percentages of correct answers about the concepts of freezing

Grade Concepts	4	5	6	7	8	9	10	11	12
Identical matter	33(38%)	39(46%)	42(44%)	68(62%)	53(66%)	65(71%)	88(91%)	85(89%)	75(81%)
Recoverability	49(57%)	46(55%)	56(59%)	76(70%)	65(81%)	80(87%)	90(93%)	88(92%)	90(97%)
Conservation of mass	30(35%)	22(26%)	20(21%)	42(39%)	27(34%)	37(40%)	60(62%)	66(69%)	68(73%)
Total in each grade	86	84	95	109	80	92	97	96	93

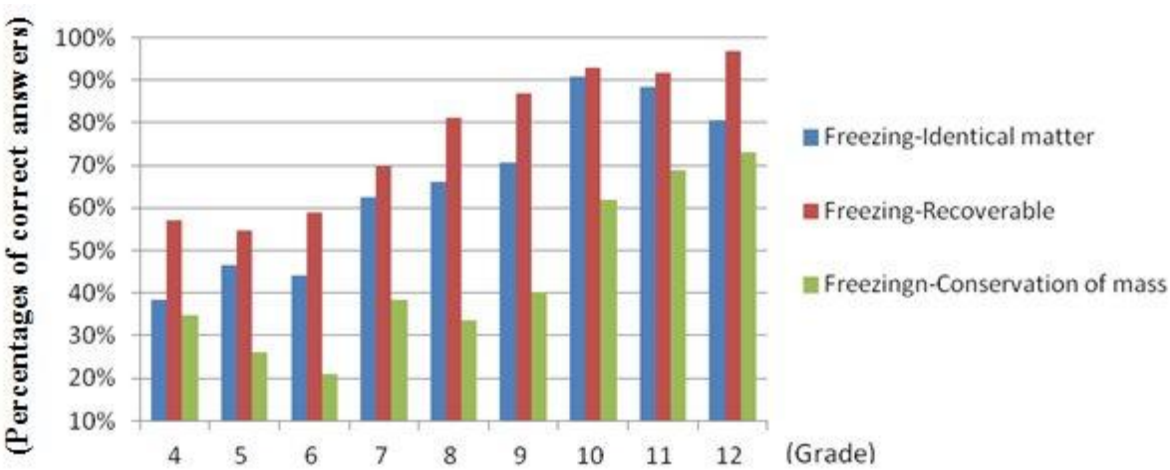

Figure 2. The bar chart of percentages in freezing

In evaporation, the results were shown in Table 3 and Figure 3.

Table 3. Count and percentages of correct answers about the concepts of evaporation

Concepts \ Grade	4	5	6	7	8	9	10	11	12
Identical matter	22(26%)	31(37%)	13(14%)	39(36%)	44(55%)	51(55%)	67(69%)	67(70%)	64(69%)
Recoverability	38(44%)	36(43%)	37(39%)	47(43%)	41(51%)	69(75%)	75(77%)	81(84%)	73(78%)
Conservation of mass	33(38%)	30(36%)	26(27%)	34(31%)	32(40%)	42(46%)	54(56%)	58(60%)	55(59%)
Total in each grade	86	84	95	109	80	92	97	96	93

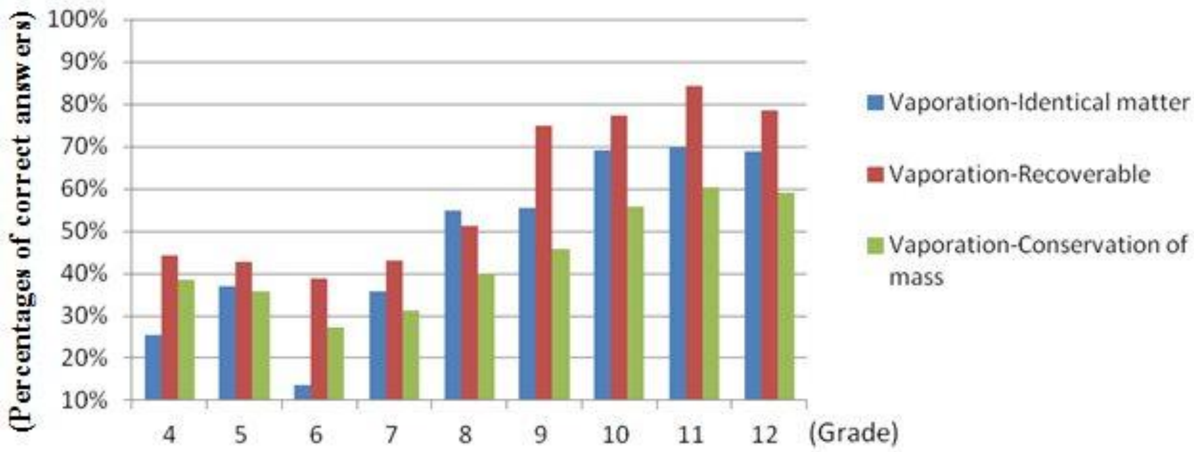

Figure 3. The bar chart of percentages in evaporation

In comparison with Figure 2 and Figure 3, over half of students who understood identical matter were from seventh grade in freezing and from eighth grade in evaporation. In recoverability, over half of students offered the correct responses in fourth grade and above in freezing, and in eighth grade and above in evaporation. The percentage of students who respond the correct answer in conservation of matter reached over 50% from seventh grade in freezing concepts and from eighth grade in evaporation concepts.

To sum up, students' concepts of freezing tended to develop earlier then concepts of evaporation. Therefore, this study adopted the paired-sample T test to analyze the learning differences. The results showed in Table 4.

Table 4. Paired-Sample T Test of learning developments in freezing and evaporation

Concepts	Identical matter			Recoverability			Conservation of mass		
	Mean	t	*p*	Mean	t	*p*	Mean	t	*p*
Freezing	60.89	6.14**	<.00	71.11	6.65**	<.00	41.33	.34	=.74
Evaporation	44.22			55.22			40.44		

**$p<.00$

In Table 4, the means of percentages in learning of freezing were all higher then learning of evaporation. The learning differences between freezing and evaporation reached the significant differences only in identical matter and recoverability, but not in conservation of mass.

3. The correlation analysis between students' learning of microscopic particles and two phenomena, freezing and evaporation.

This study investigated the correlation of students' learning of microscopic particles concepts to two phenomena in three stages, primary school (fourth to sixth grade), junior high school (seventh to ninth grade) and senior high school (tenth to twelfth grade). The results showed in Table 5.

Table 5. Pearson's correlation between students' learning of microscopic particles and phase transitions

Stage		Result
Primary school	Person Correlation	.37**
	Sig. (2-tailed)	.00
	Sum of Squares and Cross-products	5457.19
	Covariance	20.67
	N	265
Junior high school	Person Correlation	.50**
	Sig. (2-tailed)	.00
	Sum of Squares and Cross-products	13654.66
	Covariance	48.77
	N	281
Senior high school	Person Correlation	.54**
	Sig. (2-tailed)	.00
	Sum of Squares and Cross-products	15604.13
	Covariance	54.75
	N	286

**p<.00

The results in Table 5 showed that the high correlations were found from .37 to .54.

DISCUSSION AND CONCLUSIONS

1. The percentages of students' understanding of microscopic concepts increased sharply from ninth to tenth grade.

According to Piaget's cognitive developmental theory, the most of middle school students should reach the abstract thought stage and be able to understand microscopic concepts. But, in this survey, the results in Figure 1 were not shown as expected (Wu & Chiu, 2013b). In addition, both of students' concepts did not come to the plateau period until tenth grade when the learning of microscopic particles advanced. This can be explained that there were few teaching materials of particles in early middle school in Taiwan and Martin et al. (2004)'s research also indicated the similar results in other countries.

2. The learning development of freezing and evaporation reached the significant differences in identical matter and recoverability.

Both of the two phase transitions, freezing and evaporation, belonged to physical change depending on pressure and temperature conditions. Although students' conceptual development followed a similar increasing trend, there were still the significant differences between them (shown in Table 4) in identical matter and recoverability but not in conservation of mass. Obviously, students' concepts of freezing developed earlier then the concepts of evaporation. It was clear that students did not understand the two phenomena on the basis of principles of phase transitions.

3. There were the high correlations between concepts of microscopic particles and two phenomena, freezing and evaporation.

The concepts of microscopic particles can be the basis for students to learn phase transitions (Wu & Chiu, 2013a) and promote students to understand freezing and evaporation via the identical principles, namely, microscopic particles. And the result showed the statistically significant correlations. According to Vosniadou (2002), belief and presuppositions can restrict students' mental model and the knowledge acquisition process. With concepts of microscopic particles, students can reduce misconceptions of phase transitions in following teachings.

In conclusion, in this study it was inferred that the key to learning differences between freezing and evaporation was students' lack of microscopic particles concepts. Chi (2005) argued that the first step to conceptual change is to acquire the correct ontological categories. Students may enhance the concepts of phase transitions while understanding microscopic processes of phase transitions as an emergent process. Therefore, the appropriate teaching sequence would include microscopic particles concepts before teaching of phase transitions.

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REFERENCES

Benson, D. L., Wittrock, M. C., & Baur, M. E. (1993). Students' preconceptions of the nature of gases. *Journal of research in science teaching, 30*(6), 587-597.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences, 14*(2), 161-199.

Coştu, B., Ayas, A., & Niaz, M. (2010). Promoting conceptual change in first year students' understanding of evaporation. *Chemistry Education Research and Practice, 11*(1), 5-16.

Harrison, A. G., & Treagust, D. F. (2002). The particular nature of matter : challenges in understanding the submicroscopic world. In J. K. Gilbert, O. D. Jong, R. Justi, D. F. Treagust & J. H. V. Driel (Eds.), *Chemical education: Towards a research-based practice* (pp. 189-212). The Netherlands: Kluwer Academic Publishers.

Johnson, P., & Papageorgiou, G. (2010). Rethinking the introduction of particle theory: A substance-based framework. *Journal of Research in Science Teaching, 47*(2), 130-150.

Martin, O., Mullis, I., Gonzales, E., & Chrostowski, S. (2004). *Timss 2003 international science report*. Boston College, MA: TIMSS and PIRLS International Study Centre.

Posner, J., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211-227.

Stavy, R. (1990). Children's conceptions of changes in the state of matter: From liquid (or solid) to gas. *Journal of Research In Science Teaching, 27*(3), 247-266.

Tsai, C. C. (1999). Overcoming junior high school students' misconceptions about microscopic views of phase change: A study of an analogy activity. *Journal of Science Education and Technology, 8*(1), 83-91.

Wu, W. L. & Chiu, M. H. (2013a). *Investigating the development and influence of Particle-oriented and Two-Stage Teaching Module via conceptual evolutionary approach*. Presented at NARST Annual International Conference, April 6 - 9, 2013, Rio Grande, Puerto Rico, USA.

Wu, W. L. & Chiu, M. H. (2013b). *Students' conceptual evolutionary pathways of phase transitions: toward empirical and theoretical approaches*. Paper will be presented at the European Science Education Research Association (ESERA) 2013, September 2th - 7th, Nicosia, Cyprus.

Vosniadou, S. (2002). On the nature of naive physics. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 61-76). Dordrecht: Kluwer.

MEASUREMENT ESTIMATION SKILLS AND STRATEGIES OF LOWER GRADE STUDENTS

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Abstract: Measurement estimation is an important part of everyday live and a higher-level competence in science and mathematics education. In order to improve estimation skills, at first, estimation abilities and strategies have to be examined. In this study, a questionnaire and an interview survey are combined in order to determine measurement estimation skills and strategies used by German students. So far, over 800 students in the grades eight to ten and 30 college juniors participated in the questionnaire survey. First results show no significant improvement of the estimation abilities for higher grades. Both; pupils and students have a lack in estimation skills. We found that estimates of physical quantities which are used quantitatively in everyday live, and/or perceptible quantities (such as temperature) were more accurate than others like force or acceleration. In addition to the questionnaire, first interviews revealed that students are untrained estimators, but also that they have too high confidence in their own estimates. Besides this, a whole number of different estimation strategies could be identified, confirming those known from previous estimation studies in mathematics, but expanding the range to physical quantities such as force or velocity, where new strategies like 'physical decomposition' were observed.

Keywords: measurement estimation, accuracy, strategies

INTRODUCTION

Estimation ability is an interdisciplinary competence. It has a great relevance in mathematics and natural sciences. It is not only used in the laboratory or the classroom, but is essential also in everyday live. Furthermore, estimation is often the only possible way to achieve a result, for example if measurements are impossible, or if not all data are known, or if the situation is too complex for exact calculations. Making estimates is timesaving and can give a quick overview of the situation. It can also serve as a basis for decision making, not only in science, but also in economics and even politics. For these reasons, one important aspect of natural science education is to enable students to make accurate estimates. However, in physics education, measurement estimation is mostly taught implicitly. In Germany, measurement estimation is even only part of elementary school education in mathematics. But is this sufficient? How can estimation skills be improved? Which estimation strategies emerge, which are most successful?

State of Research

Studies in the field of mathematical education over the last 60 years have shown that both students and adults have great deficits in their ability of measurement estimation (Crawford & Zylstra, 1952; Reys et al. 1982; Hildreth, 1983; Crites, 1992; Joram et al., 2005). But almost all of the studies existing so far have focused on quantities like numbers, length or area, which play an important role in mathematics. Only a few studies included some physical quantities like velocity, time or temperature (e. g. Corle, 1960; 1963). The principal aim of this study is to fill in this gap and to investigate the estimation ability of students concerning quantities which are commonly used in the physics classroom. Additionally, estimation strategies will be analyzed.

METHODS

Given the aim of investigating the estimation abilities and strategies used by students for different physical quantities, a broad range of estimation tasks has been developed. First, a questionnaire to determine the accuracy in measurement estimation was designed; second, interview questions were formulated to identify the estimation strategies. Additionally, some of the questionnaire and interview tasks involved the request to quote the accuracy of the own estimation just made. The study deals with physical quantities length, mass, time, temperature, area, volume, density, acceleration, speed and force. A first run of the questionnaire survey also included more abstract quantities like energy, power and current. For each quantity, there were at least four different everyday life objects or activities to estimate (TEO: 'to estimate object') in order to determine the accuracy of the given estimations for the given quantity. The estimation tasks were structured in five everyday situations. In Figure 1 the first estimation situation is shown as an example.

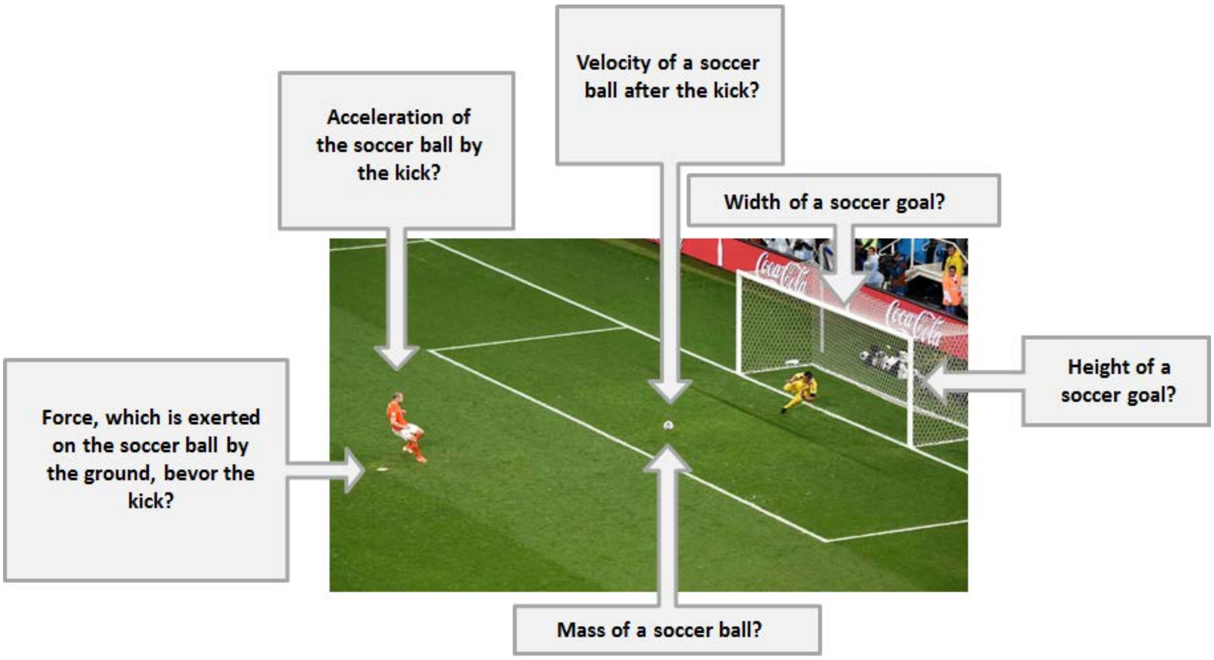

Figure 1. Everyday life situations as shown in the example give the context for the estimation task for the different physical quantities.

The aim of the interview survey was to identify strategies used by students to generate estimates. There were two different types of estimation tasks: measurement estimation problems in which the TEO was physically present and problems in which it was physically absent. Again, the accuracy of the estimates was determined; and afterwards the estimation strategies were analyzed.

Pilot tests of the questionnaire and the interview guideline were conducted on a small number of students to ensure that children are familiar with TEOs and are able to understand all involved tasks.

By now over 800 grammar school pupils from North Rhine-Westphalia and Lower Saxony in the grades eight to ten (14-16 years) participated in the questionnaire. In addition over 30 first-year college students took part as comparison group.

RESULTS

The results are separated in two sections: (1) the accuracy of the measurement estimations for different quantities and (2) the used measurement estimation strategies.

Accuracy

In order to determine the accuracy of the given estimates the mean ratio of each estimate and the related TEO was calculated for each student and physical quantity.

$$accuracy_{quantity} = \sum_{i=1}^{n} \frac{estimate_i}{TEO_i}$$

An accuracy value of one represents perfect estimates, a value above one indicates that the student tents to overestimate this quantity and a value beneath one indicates an underestimation of this student on average. In Figure 2 the resulting boxplots for each quantity are shown. It can be seen that lower grade students are rather good in estimating length and temperature. Over 50% of the given estimates are within the range of -50% to +100% of the TEO. In mean, the quantities velocity, force, area and volume were underestimated by the students, especially force and volume with over 50% of the estimates less than half the size of the TEO. In contrast, more than half of the students tend to overestimate the quantities mass, time, acceleration and density. Particularly striking are the estimates concerning time and density. Over 75% of the students overestimate times by a factor of two. The large variations of the estimation ability can be seen especially in the accuracy of the estimates concerning density. The range of the given estimates varies strongly, as can be seen on the length of the box, which represents the range of the middle 50% of the estimates. Again, length and time are the quantities for which not only the highest accuracy in the estimates could be identified, additionally almost all students show similar estimation abilities (small box length).

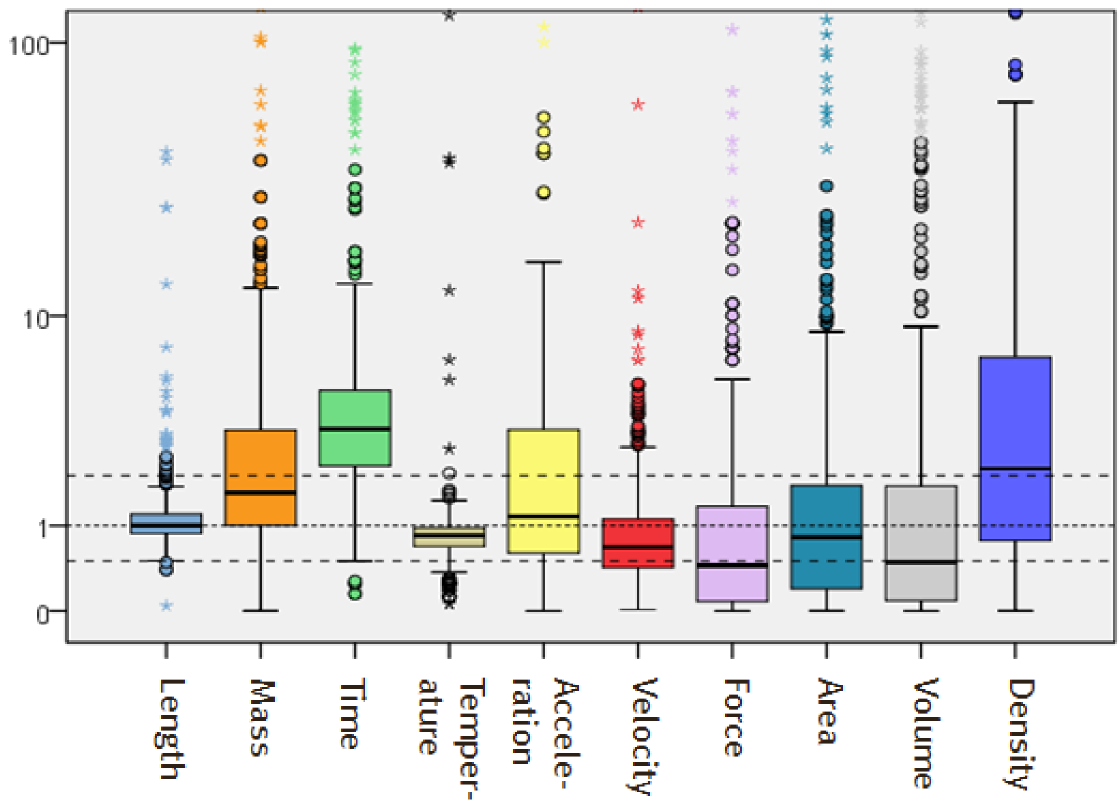

Figure 2. Box-plots of estimates given by the students in the questionnaire survey. Presented are the mean ratio of the estimates to the TEOs, the dashed lines represent a deviation of -50% to +100% to the TEO.

The questionnaire survey showed almost no increase in the measurement estimation ability between the grades eight to ten and first-year college students. There were no significant differences between the grades eight and ten and only significant differences in the estimation ability concerning the quantities mass, acceleration (8^{th} grade vs. students), Temperature (8^{th}, 10^{th} grade vs. students) and force (10^{th} grade vs. students).

Additionally, only the minority of expected correlations between the estimation ability of interconnected quantities like length and area could be verified. For this purpose, the Spearmans correlation coefficient was determined for each combination of investigated physical quantities. Small positive significant correlations (**$p \leq 0.01$) could only be found in the combinations of area and volume (r_s=.214** to r_s=.337**) and acceleration and velocity (r_s=.267** to r_s=.302**).

Also of interest is, that for the majority of students no significant correlation between the physical expertise and their estimation ability was determined.

Strategies

The analysis of the 31 interviews confirmed the questionnaire results concerning the accuracy of the estimation ability of students for different quantities. Here again the estimates of Length and Temperature were most accurate.

The analysis of the used strategies showed that students use various strategies when estimating physical quantities. Strategies that have been described in previous mathematical education studies, for instance by Forrester et al. (1990), Hildreth (1983), Joram et al. (1998) and Siegel et al. (1982), could be recovered. Additionally, some new adequate strategies like *'Physical Decomposition'* could be discovered. In total, students applied 31 different estimation strategies separated in four main categories (see Figure 3).

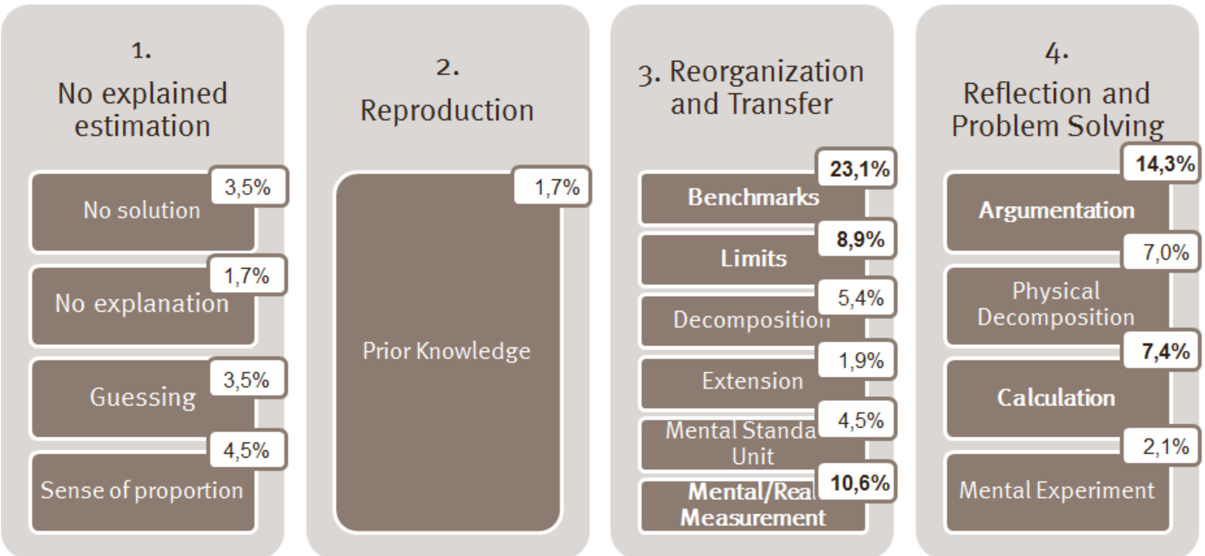

Figure 3. Estimation strategies used by the students. The percentages are normalized to the total number of estimation strategies used by all students in the interviews.

The most commonly used strategies were *Benchmarks* (23%), *Argumentation* (14%), *Physical Decomposition & Calculation* (14%), *Mental / Real Measurement* (11%) and *Limits* (9%). The use of *Benchmarks* means in general the comparison of a known standard or familiar object with known size to the TEO. For example, in order to estimate the height of a door one could imagine the own body height and compare this height with the door to generate an estimate. By using the *Argumentation* strategy one justifies the estimation on every day or physical knowledge. For instance the temperature of a pocket warmer has to be below 100°C, since otherwise the user would burn himself. The *Physical Decomposition & Calculation* simply describes the decomposition of the TEO into subTEO, which can be estimated easier. Subsequently, the subTEOs are combined with the help of a known formula. One example for this strategy is the decomposition of a rectangle in its length and width. After estimating these subTEOs, the area can be determined by multiplying the length and width. When using a *Mental / Real Measurement* students imagine either a measurement device next to the TEO reading the value mentally or they use an object with known size as measurement instrument (e.g. finger range). Another often used strategy is the statement of *Limits*. In this case students indicate instead of a specific estimate a range with lower and upper limit in which they suspect the size of the TEO.

The choice of the applied strategy is independent of the age of the asked student, 8th grade pupils and first-year students show no significant differences in their strategy choice.

The applied strategy is also in the majority of the cases independent of the physical presence or absence of the TEO. Only exceptions are the quantities length and area. If the TEO is present while a length or area estimation, students tend to apply more real measurements, for example by using their finger range as measurement instrument.

Strategies, which led to most accurate and most inaccurate estimates, are listed in Table 1. Nearly always one of the most used strategies leads to accurate estimates concerning at least one physical quantity. Only exception is the *Argumentation*, although *Argumentation* is in total the second most used strategy, the use of this strategy does not imply an accurate estimate. Quite the contrary seems to be true. Estimates, which base mainly on *Everyday Argumentation*, are often inadequate. For five of the ten physical quantities the use of *Everyday Argumentation* leads with a high probability to inaccurate estimates. Apart from *Everyday Argumentation* the use of *Benchmarks*, *Real Measurement*, *Pseudo Physical Decomposition* and *Calculation (inadequate)* increase the probability of inadequate estimates.

The use of *Benchmarks* can lead to accurate estimates as well as to inaccurate estimates. The crucial factor when applying *Benchmarks* is the correct size of the known standard or familiar object. Although students, who imagine the comparison object with an incorrect size, may apply the *Benchmark* strategy correctly, they still achieve an inaccurate estimate due to the deviation between the real and their assumed size of the used comparison object. The same problem appears when using the *Real Measurement* strategy. As long as the assumed size of the known object, which is used as measurement instrument, is not identical with its real size this strategy will unavoidable lead to inaccurate estimates. Another not promising strategy is the *Pseudo Physical Decomposition*. Just as in the *Physical Decomposition* students start to break down the TEO into subTEOs, but instead of combining the subTEOs subsequently, they break off at this point. This may be due to the unawareness of the appropriate formula. Often the students switch after this failed estimation try to the *Everyday Argumentation* strategy. When using the *Physical Decomposition & Calculation* strategy main causes for inaccurate estimates are the use of an inappropriate formula (inadequate calculation) and the proceeding calculation of the TEO with previously inaccurate estimated subTEOs (adequate calculation).

Table 1. Strategies leading with high probability to accurate and inaccurate estimates for each physical quantity.

Physical quantity	Strategies used for most accurate estimates	Strategies used for most inaccurate estimates
Length	Benchmarks	Benchmarks (incorrect assumed size of Benchmark)
Mass	Benchmarks	Everyday Argumentation & Sense of Proportion
Time	Mental / Real Measurement	Real Measurement (incorrect assumed size of measurement instrument)
Temperature	Benchmarks & Limits	Everyday Argumentation
Area	Physical Decomposition & Calculation (adequate)	Physical Decomposition & Calculation (adequate, but incorrect size of subTEOs or inadequate)
Volume	Benchmarks	Extension
Velocity	Physical Decomposition & Calculation (adequate)	Pseudo Physical Decomposition & Everyday Argumentation
Force	Mental / Real Measurement	Everyday Argumentation
Density	Physical Decomposition & Calculation (adequate)	Pseudo Physical Decomposition & Everyday Argumentation
Acceleration	Physical Decomposition & Calculation (adequate)	Benchmarks, Physical Decomposition & Calculation (inadequate)

DISCUSSION AND CONCLUSIONS

The study showed that pupils as well as college students are pretty good in estimating length and temperature. In contrast, they are poor estimators for abstract quantities such as acceleration or density. This is partly due to the lack of accurate Benchmarks, as well as due to the unawareness of appropriate formulas for calculating these quantities based on subTEOs.

No significant correlation between the estimation ability and mathematical and physical knowledge is detectable. A significant correlation of estimation abilities could only be verified for the directly related quantities “area and volume” and “acceleration and velocity”.

Since there is no significant increase in the estimation ability between the eighth grade and graduation, it can be assumed that teaching estimation skills implicitly does not work well. Our results also showed no differences in the strategy use for lower grade and first-year college students. This indicates, that students do not develop new estimation strategies. Therefore, it is necessary to improve the education concerning estimation abilities using those strategies which lead to the most accurate estimation results. The importance of a good estimation ability in daily live is obvious. Students must be given sufficient occasion to develop and practice their skills. The training of measurement estimation beyond the elementary school in mathematics and science could further increase the estimation ability of students, especially since many physical quantities are first introduced in higher grades.

One possible approach to increase the estimation ability of students is the development of an adequate benchmark system and the explicit training of different estimation strategies, since results up to now indicate that students are good estimators if they have a distinctive repertoire of adequate benchmarks for basic quantities (length, mass, time and temperature) and know how to determine derived physical quantities (are, volume, velocity, etc.) from basic quantities. In contrast, if students use Benchmarks with an incorrect assumed size or do not have the physical knowledge to calculate physical quantities based on underlying subTEOs, the probability for inaccurate estimates increases strongly (see. Tab. 1).

REFERENCES

Corle, C. (1960). A Study of the Quantitative Values of Fifth and Sixth Grade Pupils. *The Arithmetic Teacher*, 7, 333-340.

Corle, C. (1963). Estimates of quantity by elementary teachers and college juniors. *The Arithmetic Teacher*, 10, 347-353.

Crawford, B. & Zylstra, E. (1952). A Study of High School Seniors Ability to Estimate Quantitative Measurements. *The Journal of Educational Research*, 46, 241-248.

Crites, T. (1992). Skilled and Less Skilled Estimators' Strategies for Estimating Discrete Quantities. *The Elementary School Journal*, 92, 601-619.

Forrester, M., Latham, J. & Shire, B. (1990). Exploring Estimation in Young Primary School Children. *Educational Psychology*, 10, 283-300.

Hildreth, D. (1983). The Use of Strategies in Estimating Measurements. *The Arithmetic Teacher*, 30, 50-54.

Joram, E., Subrahmanyam, K. & Gelman, R. (1998). Measurement Estimation: Learning to Map the Route From Number to Quantity and Back. *Review of Educational Research, 68, 4013-449.*

Joram, E., Gabriele, A., Bertheau, M., Gelman, R. & Subrahmanyam, K. (2005). Children's Use of the Reference Point Strategy for Measurement Estimation. *Journal for Research in Mathematics Education*, 36, 4-23.

Reys, R., Rybolt, J., Bestgen, B. & Wyatt, J. (1982). Processes Used by Good Computational Estimators. *Journal for Research in Mathematics Education*, 13, 183-201.

Siegel, A., Goldsmith, L. & Madson, C. (1982). Skill in Estimation Problems of Extent and Numerosity. *Journal for Research in Mathematics Education*, 13, 211-232.

PROMOTING STUDENTS' UNDERSTANDING OF SCIENTIFIC INQUIRY THROUGH EXPLICIT INSTRUCTION: RESULTS OF A CLASSROOM-BASED INTERVENTION

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Abstract: Promoting students' knowledge and abilities of scientific inquiry (SI) is a central goal of science education. While it is generally agreed that students may not learn SI without engaging in hands-on inquiry activities, it is not yet clear how such activities have to be embedded in instruction in order to be effective. Research presented in this paper utilizes a treatment-control design to investigate the impact of an explicit and an implicit instructional approach on the development of students' knowledge and abilities of SI. Both approaches were embedded into a classroom-based intervention conducted in a German upper secondary school (N = 240). During the intervention the students worked together in groups of two or three; approximately fifty percent of these groups were documented on video. Students' knowledge and abilities of SI were assessed before and after the intervention using a paper-pencil test instrument. Additional data were collected prior to the intervention to assess students' subject-matter knowledge and to allow for control of dispositional factors (e.g., cognitive abilities, interest in physics). Paper-pencil data collected were analysed using Rasch measurement techniques and repeated measures ANOVA. Results indicate that not only explicit but also implicit instruction fosters students' knowledge and abilities of SI; however, explicit instruction appears to be substantially more effective. Furthermore, linear regression analyses were conducted to investigate the impact of students' subject-matter knowledge and their prior knowledge and abilities of SI on the effectiveness of explicit / implicit instruction. Findings suggest that the intervention was equally effective for all students regardless of their prior knowledge. A preliminary attempt to link the paper-pencil and the video data collected is presented and a first approach for a video based analysis of students' learning processes in an implicit and an explicit instructional approach is discussed.

Keywords: scientific inquiry abilities; explicit and implicit instruction; student learning

INTRODUCTION

Enabling students to engage successfully in scientific inquiry (SI) is considered as an important part of scientific literacy and therefore a central goal of science education (e.g., Millar & Osborne, 1998; NRC, 2012; KMK, 2005). In line with the Framework for K-12 Science Education (NRC, 2012), we consider SI as knowledge and abilities necessary to *do* scientific inquiry[1]. Consequently, abilities of SI have to be differentiated from knowledge *about* inquiry, which can be considered as a facet of nature of science (cf. Lederman, 2007). Across the research literature and policy documents three SI abilities (and associated knowledge) are frequently mentioned and may, therefore, be considered as key abilities of SI: 1) Formulating scientific questions and hypotheses, 2) planning a scientific investigation and 3) evaluating and interpreting data (e.g., Cuevas et al., 2005; Klahr & Dunbar, 1988; NRC, 2012). Research presented in this paper explores the effectiveness of two different instructional approaches (implicit vs. explicit) on these three key abilities.

THEORETICAL BACKGROUND

Researchers and policy-makers agree that students' participation in inquiry activities can lead to an improvement of their knowledge and abilities SI (e.g., NRC, 2012; Minstrell, 2000).

However, it is not clear how inquiry activities have to be embedded in instruction in order to be effective (Zimmerman, 2007). One assumption is that "doing inquiry" may not be sufficient to develop knowledge and abilities of SI, rather, inquiry activities have to be embedded in instruction which directly targets corresponding concepts (e.g., Minstrell, 2000). This means that developing knowledge and abilities of SI requires opportunities for students to do inquiry *and* to reflect upon the concepts relevant for conducting inquiry in a scientific manner. Even though the importance of the "reflection" has been advocated by researchers (e.g., Khishfe & Abd-El-Khalick, 2002; Minstrell, 2000), mainly the "doing" of inquiry is frequently highlighted as the key factor of instruction (e.g., NRC, 2012). Exposing students to instruction that includes both inquiry activities and concepts on how to do inquiry is what we refer to as explicit instruction. In contrast, we understand implicit instruction as solely "doing" inquiry assuming that students will not only develop abilities but also discover underlying concepts "automatically" during the inquiry process (cf. Alfieri, Brooks, Aldrich & Tenenbaum, 2011). So far, only for the Control of Variables Strategy (CVS), an important aspect of "planning a scientific investigations", have the effects of explicit and implicit instruction been investigated comparatively (e.g., Chen & Klahr, 1999; Dean & Kuhn, 2007; Lazonder & Egberink, 2014; Ross, 1988). Results of these studies indicate that explicit instructional approaches are more effective in promoting students' abilities to use CVS then implicit instructional approaches. Moreover, implicit approaches only seem to have a positive effect on students' CVS abilities if they are implemented over an extended period of time (ten weeks or more). These findings could potentially provide important information for teaching that seeks to promote students' knowledge and abilities of SI. However, as CVS is only one out of many important facets of SI, findings from the studies on CVS cannot be generalized to other abilities of SI without further evidence.

Research reported in this paper utilizes paper-pencil and video based data sources to investigate the effect of an explicit and an implicit instructional approach on students' learning of three key facets of SI (formulating scientific questions and hypotheses, planning scientific investigations, evaluating and interpreting data). The research questions are:

1. What effect does explicit and implicit instruction have on promoting students' knowledge and abilities of SI?
2. What impact does students' prior SI knowledge and their subject-matter knowledge have on the effect of explicit / implicit instruction?

DESIGN AND METHODS

Participants

The classroom-based intervention was conducted at the end of 2013 in one German upper secondary school and consisted of three stages: Pre-test, intervention, post-test. The participants (N = 204) were 16-17 year old students (65.2% female) from twelve 11th grade classes. The twelve classes were divided into six treatment and six control groups. In order to ensure comparability between the classes assigned to the treatment and control group, students' subject-matter knowledge, SI knowledge, cognitive abilities, interest in physics, and self-concept were gathered (cf. Table 2). Results of independent t-tests showed that differences between means of the treatment and the control group are small and not statistically significant for all investigated variables (significance level $p <.05$). Therefore, it is assumed that both groups are similar and can thus be compared.

Intervention

The intervention comprised three units at a weekly basis (Table 1); the units lasted 45 or 90 minutes. Students worked in small groups of two or three with classmates of their own choice.

All tasks and information were written down in order to minimize student-teacher interaction so that classes and student groups can be compared. The units for the treatment and control classes (Table 1) comprise the same physics content and use the same hands-on experiments, but differ with respect to their focus on SI: The units for the treatment classes *explicitly* address SI, for instance, by providing concepts ("Change only one variable at a time") or prompting students to apply these concepts in inquiry tasks ("Formulate a scientific questions that can be answered with this experiment"). Instruction for the control classes contains only *implicitly* aspects of SI, for example, by stating a scientific question at the beginning of an experiment or by following the control of variables strategy in experimental instructions. In contrast to the explicit instruction, the implicit instruction did not prompt students to reflect upon, for instance, the structure or the nature of the questions, the way the experiments were pre-designed for them, or why data had to be plotted in a particular way. In order to control for duration, the units for the control classes expand slightly on the science content (e.g., more calculation).

Table 1
Content of the three learning units for treatment and control classes

	Physic content	Treatment focus	Control focus	Duration
Unit I	Pressure in fluids	Formulating scientific questions and hypotheses	Model of hydrostatic pressure, calculation of hydrostatic pressure, etc.	~45 minutes
Unit II	Free fall and aerodynamic drag	Planning scientific investigations	Parameters influencing average speed during a fall, existence of terminal speed, etc.	~90 minutes
Unit III	Trajectory of projectiles and ballistic curves	Analyzing and interpreting data	Parameters influencing the maximum height and width of throws, trajectories with and without drag, etc.	~90 minutes

Data Sources

The study presented in this paper uses two different data sources to investigate students' learning of SI abilities: paper-pencil data and video data.

Paper-pencil data were collected utilizing a pre-post-test design. Before and after the intervention, students' knowledge of SI was assessed with a paper-pencil test. In addition, a subject-matter knowledge test and three short tests and questionnaires on cognitive abilities, interest in physics, and self-concept were administered to the students prior to the intervention. The quality of each instrument was evaluated using Rasch measurement techniques (cf. Boone, Staver & Yale, 2014). Statistical and psychometric indices suggest good instrument function and reliability (Table 2).

Table 2
Overview of instruments employed in the study and their psychometric indices

	Inquiry Knowledge[1]	Subject-Matter Knowledge[2]	Cognitive Abilities[3]	Interest in Physics[4]	Self-Concept[5]
Used in	Pre-test, Post-test	Pre-test	Pre-test	Pre-test	Pre-test
Duration	35 minutes	25 minutes	8 minutes	5 minutes	5 minutes
min. Outfit MNSQ	0.71	0.71	0.53	0.65	0.64
max. Outfit MNSQ	1.16	1.16	1.48	1.72	1.87
Person Reliability	.81	.74	.80	.83	.95
Item Reliability	.97	.98	.94	.98	.97

Notes. The instruments used are described in the following references listed below.
1: Vorholzer, von Aufschnaiter, and Kirschner (2016)
2: Alonzo and Steedle (2009); Hestens, Wells, and Swackhammer (1992)
3: Heller and Perleth (2000)
4: Hoffmann, Häußler, and Haft-Peters (1997)
5: Jerusalem and Satow (1999)

Video data were collected from approximately fifty percent of the students in both treatment and control group during all sessions of the intervention (Figure 1). In each of the 12 classes three to four groups of two to three students were recorded. The groups were selected solely depending on whether they had given their consent to being recorded.

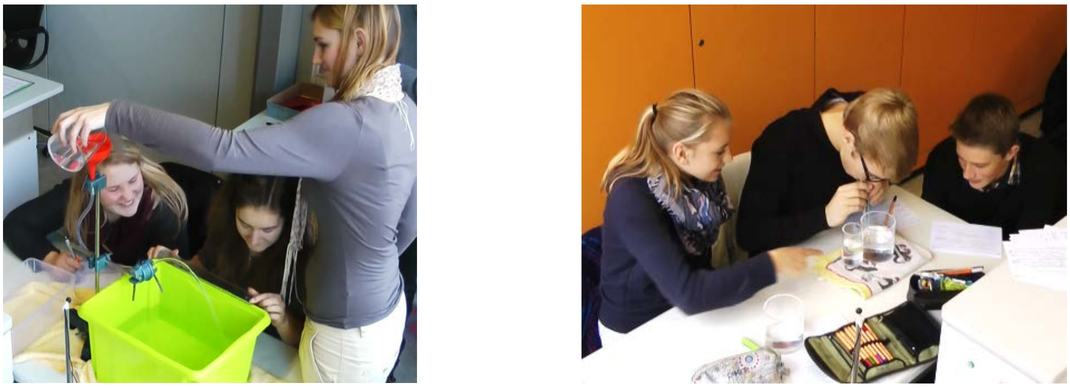

Figure 1. Screenshots from the video data recorded during the intervention.

RESULTS OF THE PRE-POST-COMPARISON AND DISCUSSION

Pre- and post-test SI measures from treatment and control groups were investigated using repeated-measures ANOVA. Results reveal that both the treatment and the control group improved significantly from pre- to post-test (treatment group: $F(1, 64) = 56.36$, $p < .001$, control group: $F(1, 64) = 23.10$, $p < .001$). However, the difference between pre- and post-test SI knowledge measures is significantly higher for the treatment than for the control group ($F(1, 128) = 9.46$, $p = .003$, $\eta^2 = .069$; Figure 2). These results suggest that explicit *and* implicit instruction can foster students' knowledge and abilities of SI, but explicit instruction is substantially more effective. On the one hand, our results increase the generalizability of previous findings on the effect of *explicit* instruction on students' learning of CVS (Chen & Klahr, 1999, Lazonder & Egberink, 2011; Ross, 1988), as we have shown that those findings also apply to three key abilities of SI. On the other hand, our results seem to contradict previous findings on the ineffectiveness of *implicit* instruction, as we observed a significant increase of students' knowledge and abilities of SI in the control group as well.

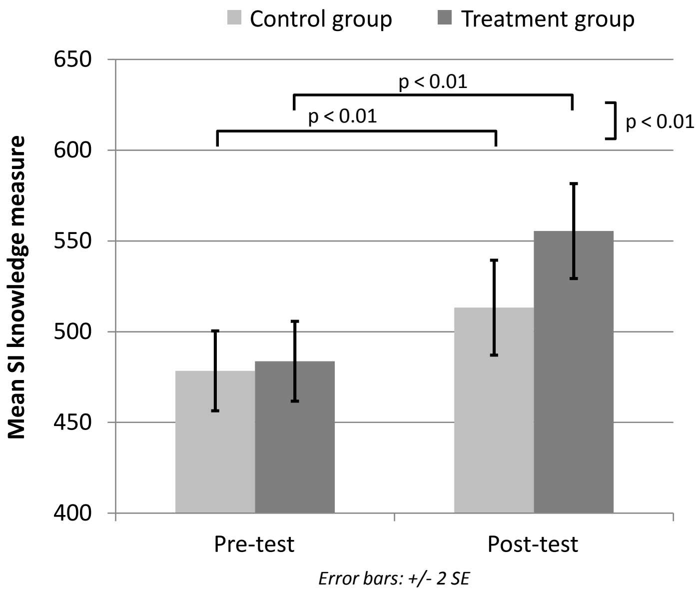

Figure 2. Mean SI measure of treatment and control group in pre- and post-test.

Results from linear regressions analyses reveal that neither students' subject-matter knowledge nor their prior SI knowledge is a meaningful predictor for the pre- to post difference in their SI knowledge measure (all β-values < 0.2 and not significant at a level of $p < 0.05$; Figure 3). These findings suggest that both instructional approaches are equally beneficial for all students, regardless of any differences in their subject-matter knowledge and their prior knowledge of SI. These findings also demonstrate that it is possible to promote students' knowledge and abilities of SI equally, despite differences in their prior knowledge.

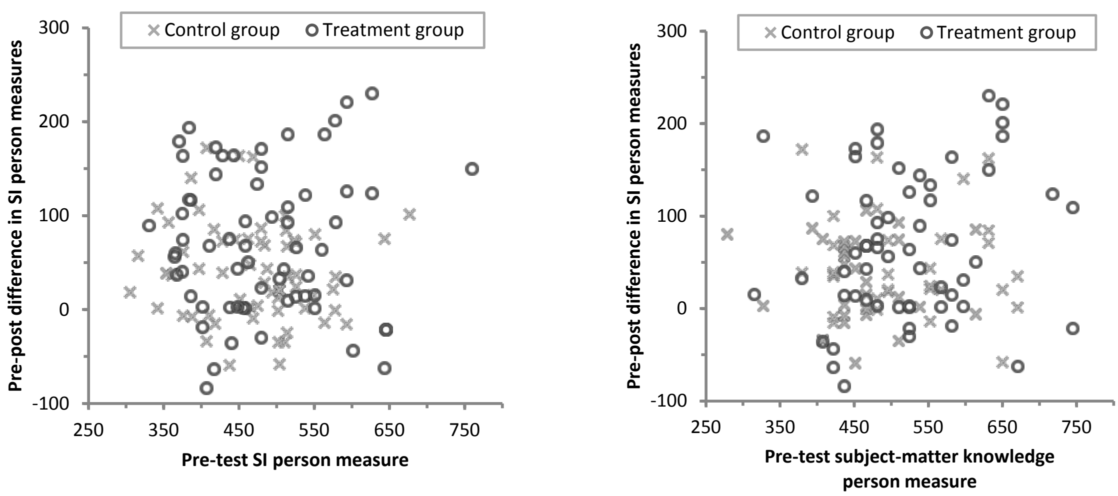

Figure 3. Crossplot of students' pre-test SI measures (left, horizontal axis) respectively subject-matter measure (right, horizontal axis) and their learning gains (pre to post) in SI abilities (vertical axis).

Overall, the results differ in two ways from typical outcomes of research on students' knowledge and abilities of SI: (1) The implicit instruction has a significant positive effect which is contrary to results gained with the CVS (e.g. Chen & Klahr, 1999). (2) Prior subject matter and prior SI knowledge do not have a noticeable effect on students' learning of SI. A potential explanation for these differences lies in the design and the organization of the intervention, particularly in the implementation of the implicit and the explicit instruction. Chen and Klahr, for instance, used *only* probe questions in the implicit condition, e.g., "Why did you set up the comparison this way?" (Chen & Klahr, 1999, p. 1106). However, if students do not at least have an intuitive understanding of concepts about planning investigations, such probes are not likely to promote learning. In contrast, in our implementation of an implicit approach the SI concepts targeted in the explicit instruction were also used to design research questions or experimental tasks in the implicit instruction. So even though these concepts were not mentioned explicitly, the students were given multiple opportunities to discover them from the patterns of the instruction. Given variety of implementations of implicit instructional approaches (cf. Alfieri et al., 2011), it seems beneficial for future studies to further investigate similarities and differences between the effect of different implicit instructional approaches on students' learning of SI.

OUTLOOK – ANALYSIS OF VIDEO DATA

The main method of studies contrasting explicit and implicit instruction is using paper-pencil-based data sources, which do not offer much information on *how* knowledge and abilities of SI are developed during learning in these settings. Here, the use of video analysis techniques holds great potential, as these techniques can provide valuable insights into learning processes (e.g., Janik & Seidel, 2009). With regard to our study, analyzing the video data collected during the intervention could, for instance, a) be used to follow up on the abovementioned assumption about students discovering SI concepts in patterns of our implicit instruction or b) help to explore which characteristics of the intervention led to the observed non-significant impact of prior knowledge on students' learning of SI.

In order to analyse the video data collected during the intervention, a system of categories has been developed (Figure 4). The categories are, in part, derived from studies on students' processes of concept formation while working on physics tasks (von Aufschnaiter & Rogge, 2010) and aim to assess students' activities as well as how students develop and employ knowledge and abilities of SI while working on the explicit and implicit instruction.

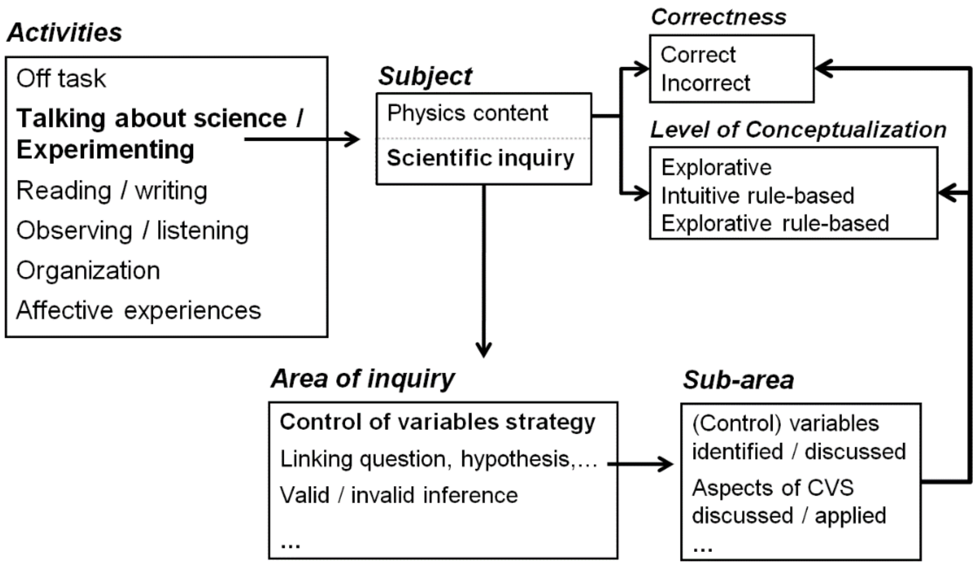

Figure 4. Preliminary coding scheme for the assessment of students' activities and concept formation

A first analysis of the video data demonstrates that both groups work on the instruction intensively and mainly come to appropriate results and conclusions. Even though off task activities seem to be rare, the students spend a noticeable amount of time on organizational issues (for instance, setting up an experiment). Moreover, preliminary findings suggest that difference found regarding the effectiveness of explicit and implicit instruction cannot solely be explained by differences in students' activities. These preliminary findings support our intention to investigate more thoroughly students' learning processes while working on the explicit / implicit instruction.

NOTES

1. It has to be noted that the NRC uses the term "scientific practices" instead of "scientific inquiry" in order to "better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires" (NRC, 2012, p. 30). However, since research presented in this paper does not focus on the whole range of practices outlined by the NRC, we decided to stay with the term "scientific inquiry".

REFERENCES

Alfieri, L., Brooks, P. J., Aldrich, N. J. & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology, 103*(1), 1–18.

Alonzo, A. C. & Steedle, J. T. (2009). Developing and assessing a force and motion learning progression. *Science Education, 93*(3), 389–421.

Boone, W. J., Staver, J. R. & Yale, M. S. (2014). *Rasch analysis in the human sciences*. Dordrecht: Springer Netherlands.

Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the control of variables strategy. *Child development*, *70*(5), 1098–1120.

Cuevas, P., Lee, O., Hart, J. & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337–357.

Dean, D. & Kuhn, D. (2007). Direct instruction vs. discovery. The long view. *Science Education, 91*(3), 384–397.

Heller, K. & Perleth, C. (2000). *Kognitiver Fähigkeitstest für 4. bis 12. Klassen, Revision: KFT 4-12+R* [Cognitive ability test for K4 to K12]. Weinheim: Beltz Test GmbH.

Hoffmann, L., Häußler, P. & Haft-Peters, S. (1997). *An den Interessen von Jungen und Mädchen orientierter Physikunterricht.* [Physics teaching oriented at the interests of boys and girls]. Kiel: IPN.

Hestenes, D., Wells, M. & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30*(3), 141–158.

Janik, T., & Seidel, T. (Eds.). (2009). *The power of video studies in investigating teaching and learning in the classroom*. Münster: Waxmann.

Jerusalem, M. & Satow, L. (1999). Schulbezogene Selbstwirksamkeitserwartung [School based self-efficacy]. In R. Schwarzer & M. Jerusalem (Hrsg.), *Skalen zur Erfassung von Lehrer-und Schülermerkmalen* [Scales for the assessment of teacher and student characteristics] (pp. 15–16). Berlin: Freie Universität Berlin.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551–578.

Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science*, *12*(1), 1–48.

KMK. (2005). *Beschlüsse der Kultusministerkonferenz. Bildungsstandards im Fach Physik für den Mittleren Schulabschluss (Jahrgangsstufe 10)* [Decisions of the Assembly of German Ministers of Education. Educational standards in physics for lower secondary school]. München: Luchterhand.

Lazonder, A. W. & Egberink, A. (2014). Children's acquisition and use of the control-of-variables strategy. Effects of explicit and implicit instructional guidance. *Instructional Science, 42*(2), 291–304.

Lederman, N. G. (2007). Nature of science: past, present, and future. In S. K. Abell & N. G. Lederman (Hrsg.), *Handbook of research on science education* (pp. 831–879). Mahwah, N.J: Lawrence Erlbaum Associates.

Millar, R., & Osborne, J. (1998). *Beyond 2000: Science education for the future: A report with ten recommendations.* London: King's College London.

Minstrell, J. (2000). Implications for teaching and learning inquiry: A summary. In J. Minstrell & E. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 471–496). Washington, D.C: American Association for the Advancement of Science.

NRC. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, D.C: National Academies Press.

Ross, J. A. (1988). Controlling variables: A meta-analysis of training studies. *Review of Educational Research*, *58*(4), 405–437.

von Aufschnaiter, C., & Rogge, C. (2010). Misconceptions or missing conceptions? *Eurasia Journal of Mathematics, Science & Technology Education*, *6*(1), 3–18.

Vorholzer, A., von Aufschnaiter, C. & Kirschner, S. (2016). Entwicklung und Erprobung eines Tests zur Erfassung des Verständnisses experimenteller Denk- und Arbeitsweisen [Development of an instrument to assess students' knowledge of scientific inquiry]. *Zeitschrift für Didaktik der Naturwissenschaften*, 1–17. doi:10.1007/s40573-015-0039-3

Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review, 27* (2), 172–223.

ENHANCEMENT OF GEOGRAPHICAL SYSTEMS THINKING THROUGH THE USE OF MODELS

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Abstract: A major goal of education in geography and its neighbouring disciplines (e.g. physics, biology) is to enhance systems thinking, which is important to deal with present and future challenges. Various ways to help achieving this goal have been proposed. The paper wants to show the potential of geographical models to help pupils to improve their systems thinking skills. In general, models can be categorised e.g. based on their function, such as visualisation and knowledge acquisition (Schubert 2013) or on the version used, e.g. hands-on and computer model. Based on the definition of geographic system competency and dimensions of system understanding drawn from the works of Viehrig et al. (in press), Rempfler & Uphues (2012), and Rieß et al. (2015), this paper will then focus on interrelations between model function and system understanding dimensions using concrete examples. Overall, based on practical experiences in using various models in geography education from primary school to university, hands-on, manipulable models seem especially suitable to enhancing pupils' systems thinking, as they not only show the structure or function of objects, but also reveal dynamics in the processes – which is necessary for higher competency levels. Moreover, model characteristics will be discussed. We are deriving preliminary design criteria for models, inter alia specific to enhancing systems thinking. Examples are the reduction of systems to their key parameters without causing misconceptions or the instruction explicitly pointing the pupils' attention to the parameters and the interactions between them. Despite the fact that system understanding has been a main goal of science education for a long time, there are only few empirical studies examining how and to what extent models help reaching this goal. The paper will conclude with first results of on-going studies testing the influence of model use on pupils' pre-concepts and systems thinking skills.

Keywords: (geographical) models in science education, systems thinking, design criteria

INTRODUCTION

Addressing present and future challenges requires for instance system understanding, creativity and constructiveness. Geography provides an important contribution to preparing children and adolescents for these challenges. Two of geography's key concepts are the view of the earth as human-environment-system and the analysis of interdependencies, with enhancing systems thinking being the major goal of geography education (DGfG 2012). Moreover, systems thinking is also one of the key goals in subjects such as physics or biology (KMK 2004, 2005). The purpose of this paper is to show the potential of geographical models to help achieving this goal.

The nature of models

According to Wirth (1979) models represent partial aspects of reality (relevant to a specific problem) as a simplified system and depict coherencies and processes. Thus, they support pupils in finding sophisticated and meaningful categories, which help them to figure out complex dynamics (Hoffmann et al. 2012). Birkenhauer (1997) recommends the use of models for supporting the comprehension of and reflection on spatial problems as well as the evaluation of possible solutions for the purpose of spatial decision-making and responsibility. A variety of possibilities to categorise models exists. For example, Schubert (2013) categorises geographical models regarding (1) form of representation (concrete, abstract), (2) function (visualisation, way of knowledge acquisition, result of cognitive processes), and (3) type (structural model, functional model, process model). Another possible categorisation is regarding the model version: (a) two-dimensional, (b) three-dimensional ("hands-on") and (3) computer simulation. Using the example of soil erosion that means for instance (a) a soil erosion map, (b) a hands-on soil erosion model (e.g. a sandbox), and (c) a soil erosion simulation, e.g. with the aid of the USLE (universal soil loss equation).

The nature of geographic system competency

According to Viehrig et al. (in press) geographic system competency has been defined as "[…] the cognitive achievement dispositions […] that are necessary to analyze, comprehend geographic systems in specific context and act adequately towards them". Different models of geographic system competency have been published:

In the theoretical model, Viehrig et al. (in press) distinguish three dimensions of geographic system competency: (1) 'comprehend and analyze systems', (2) 'evaluating possibilities to act towards systems', and (3) 'spatial thinking' – in each case with three competency levels with increasing complexity. However, not all three dimensions have been shown empirically and not all levels could be confirmed. Specifically, the second dimension could not be shown, with the remaining two dimensions being separate in one study and constituting a single dimension in another study.

In comparison, Rempfler & Uphues' (2012) theoretical model distinguishes the three dimensions (1) 'system organisation', (2) 'system behaviour', and (3) 'system adequate intention to act'. Based on empirical results, their model was condensed to the two dimensions 'system organisation and behaviour', and 'system adequate intention to act' (Mehren et al. 2015). Due to the high importance of the spatial component in geography education we combine Viehrig et al's dimensions (1) and (3) with Rempfler & Uphues' dimension (3) as shown in Table 1.

Based on the relevance of systemic model reflection presented by Rieß et al. 2015 in their theoretical system competency model, we add their dimension 'Evaluation of systemic models and of model application results', because this aspect seems not to be represented adequately in either of the above-mentioned models of systems thinking (see Table 1). This combined model with a total of four dimensions has not yet been tested empirically, but serves as a framework to explore possible links between systems thinking and model use on a theoretical level.

Models and geographical systems thinking – a promising symbiosis?

Based on Wiktorin (2013) the strong points of geographical models are (1) the visualisation of spatial issues, (2) the narrowing of complex system links to crucial features, and (3) the opportunities to structure knowledge, respectively formulate clear principles. These aspects could also help pupils to improve their system competency.

Table 1 presents possible relationships between model function and system understanding using (geographical) models. According to anecdotal experience with manifold geographical models, hands-on model manipulation seems to offer pupils the most opportunities to enhance system thinking. These models not only show the structure or function of objects (see models for “visualisation”), but also reveal dynamics (e.g. stocks & flows, feedbacks, non-linear coherencies) in the processes – which is necessary for higher competency levels in geographical systems thinking.

Table 1. Concept of interrelations between model function and system competency dimension.

GEOGRAPHICAL MODEL SERVES…		MODEL FUNCTION (cf. Schubert 2013)		
		Visualisation *(e.g. demonstration by teacher)*	**Way of knowledge acquisition** *(e.g. inquiry-based or problem-oriented experiments by pupils)*	**Result of cognitive process** *(e.g. self-construction of models by pupils at the end of a learning unit)*
DIMENSIONS OF GEOGRAPHIC SYSTEM COMPETENCY	**Comprehend and analyse systems** (cf. Viehrig et al., in press)	… to illustrate the geographical process	… as basis for pupils’ manipulation to find out system parameters and their relationships/dependencies/ feedback effects	… as reflection and consolidation of the pupils’ understanding of the geographical process
	System adequate intention to act (cf. Rempfler & Uphues, 2012; Mehren et al. 2015)	… to illustrate the consequences of different human actions	… as basis for pupils’ manipulation to find out effective/sustainable human actions	… as reflection and consolidation of the pupils’ understanding of the consequences of different human actions
	Spatial thinking (cf. Viehrig et al., in press)	… to illustrate the variations between different spatial areas	… as basis for pupils’ manipulation to find out the spatial distribution of effects of the geographical process on different parts of an area	… as reflection and consolidation of the pupils’ understanding of the variations between different spatial areas
	Evaluation of systemic models and of model application results (cf. Rieß et al., 2015)	… to illustrate the challenges regarding transferability to reality and/or validity of the model’s principles and assumptions	… as basis for pupils’ manipulation to find out the challenges regarding transferability to reality and/or validity of the model principles and assumptions	… as reflection and consolidation of the pupils’ understanding of the challenges regarding transferability to reality and/or validity of the model principles and assumptions

CASE STUDIES

Different geographical models developed at the Department of Geography, Heidelberg University of Education, visualize spatial processes and allow for their manipulation to analyze cause-effect-relationships. Here, we exemplarily present four models, which represent spatial processes in the hydrosphere, biosphere, pedosphere, and atmosphere as well as in their overlapping areas. The models are developed for different samples ranging from primary school pupils to university students.

Hydrosphere: A dam model (water reservoir) for primary school pupils

The dam model (see Figure 1) is - apart from the height - a true-to-scale model of the Sylvenstein lake in Bavaria, Germany (Northern Alps). The lake is used to regulate the water level in the lower section of one of the streams, as well as to produce energy in a hydroelectric power station. The model shows the area before the building of a dam. Three streams flow in their original meandering bed. Different positive and negative effects of damming one or more streams in the alpine area can be demonstrated in the model. Pupils can test different locations of the dam, examining the effects of the change in water level such as flooded grasslands or villages. Showing them the actual position of the dam, the pupils can also see which areas got flooded in reality, including the little village represented by the dark gray house on the right in Figure 1. Using old articles from newspapers or interviews with citizens that had to leave their home, pupils can delve further into this topic.

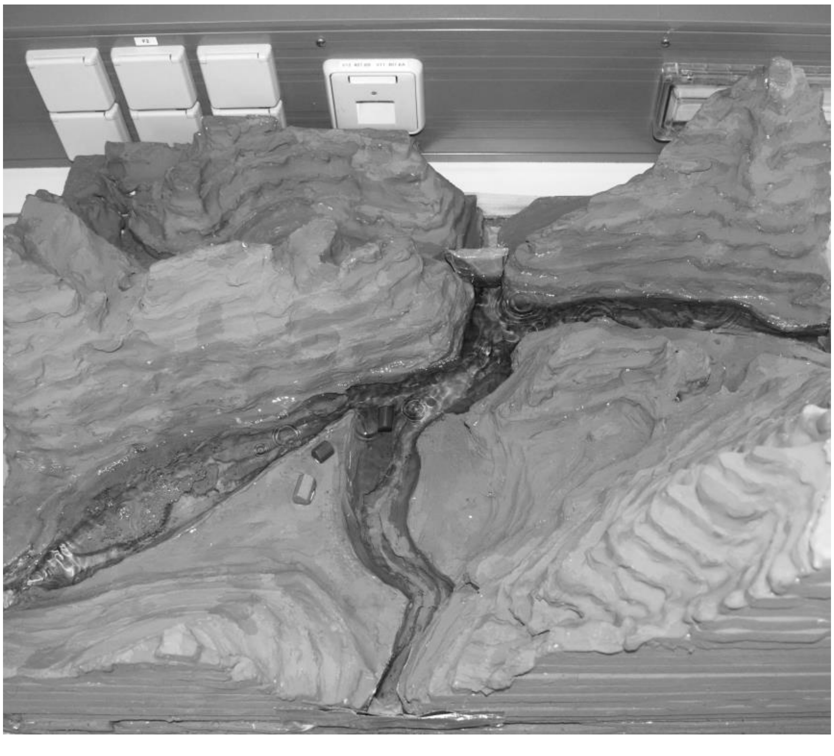

Figure 1. Dam model, water flooding in low-lying areas (own photograph).

The model emulates real surface topography. It allows pupils to examine the relationship between water inflow, dam structure, dam position and water level. Other influencing factors like water infiltration, evaporation or riverbank erosion are neglected to avoid overloading the primary school children. Taking into account possible negative effects on nature and population pupils can search for the best position for the dam by comparing different options and their consequences on population and environment, thus showing if they understood the interrelations between the parameters involved.

The model could enhance systems thinking as the pupils learn about the effects of damming water, e.g. for the production of energy, and understand impacts on the landscape as a part of the human-environment-system, e.g. the relationship between damming the water and its (un)intended effects on nature or settlement areas.

Biosphere: A windfall model (forest) for middle school pupils

The windfall model (see Figure 2) is a functional model of a landscape area of a mountain range demonstrating storm damages in forests. Different wind speeds can be simulated by using an electric fan. In this way it is possible to show how much wind speed is necessary to bring different tree species (like spruce, beech and oak) to fall – simulated by using spring hinges with different tension. In this context increasing storm or strong wind events due to climate change are discussed (see Brandt et al. 2015, Volz et al. in press). The pupils can analyse the relationships between landscape (relief), forest structure, windfall endangered tree species, different root types and other factors – e.g. by generating and testing their own hypotheses. This can help them in acquiring knowledge about the system parameters represented in the model as well as their relationship, thus developing systems thinking skills.

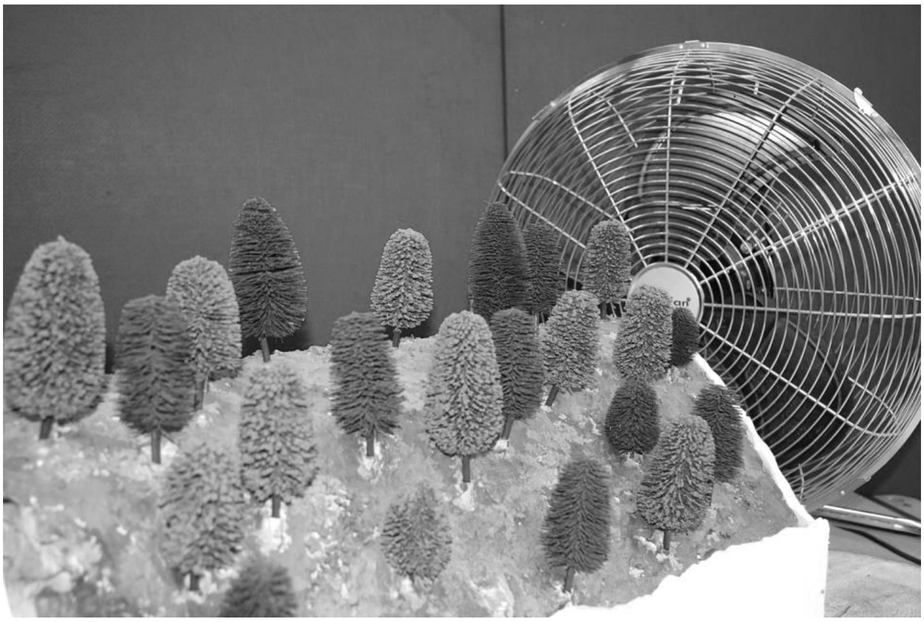

Figure 2. Windfall model (forest), wind direction parallel to ridge (own photograph).

In addition, the windfall model can be used to learn about avoiding storm damages in forests by different methods. The pupils are able to manipulate the model to identify the most effective measure (or the most effective combination of different measures such as planting a mixed forest with tiered edge) to prevent storm damages. While the main goal is to develop the pupils' comprehension of appropriate protecting measures against storm damages, they can also find out how and why storm damages vary in different mountain areas, recognising the relief as one of the major influencing factor.

However, to avoid misconceptions, the models limitations need to be discussed, which also helps pupils to evaluate the transferability between model and reality. Specifically, the model does not allow for simulation of variations in bedrock or tree ages which have a significant impact on windfall in reality.

Pedosphere: A soil erosion model (farmland) for senior high school pupils

The soil erosion models (see Figure 3) represent hillside fields during rainfall. They are made of plastic and perspex boxes and allow for adjusting surface inclination, precipitation characteristics (amount, drop size, duration), soil type, land cover, cultivation methods and other influencing factors. Surface runoff or the amount of eroded sediment is quantifiable with measuring cups respectively scales.

Figure 3. Soil erosion model, land cover reducing soil erosion compared to wasteland (own photograph).

The synoptic examination of natural and anthropogenic factors and their complex effects and interactions is a key component of the pupils' inquiry-based experiments (see Brockmüller & Jungkunst 2015). By comparing several model runs, pupils test their hypotheses about soil erosion. For example, the influences of changing climate conditions or the effects of anthropogenic interferences on erosion quantity and adaption capabilities can be investigated. Discussing appropriate adaption strategies integrates ecological, economic and social aspects of climate change in the context of sustainability and encourages individual decision-making and responsibility (see Brockmüller et al. 2015, 2016). Finally, a thorough model reflection allows the identification of discrepancies between model and reality (e.g. detailed slope topography) as well as the determination of the model's strengths (e.g. time-independence) and weaknesses (e.g. distortion by box boundaries).

Thus, pupils' systems thinking is planned to be enhanced in multiple ways in terms of the four dimensions of the competence (see also Table 1). The pupils (1) identify as many as possible influencing factors on soil erosion, (2) test, quantify and compare their effects in experiments, (3) find sustainable protection strategies taking both positive and negative impacts on man and nature into account, and (4) evaluate the transferability between model and reality.

Atmosphere: An airstream model for university students

The airstream model (see Figure 4) is a modification of a model for the demonstration of the thermohaline circulation: higher pressure leads to ascending, lower pressure to descending processes. The model is suitable especially for the demonstration of sea and land breezes, visualizing thermally induced rising air and compensation currents between high and low pressure areas by means of smoke. Thus, causes and effects of regional wind systems are illustrated. Model limits are that neither airstream velocity nor relative differences in air pressure are of measurable quantity.

Figure 4. Airstream model, enabling thermally, dynamically or orographically induced airstreams to drive propeller (own photograph).

The model can be used in a problem-based approach. One task might be to produce an air current at a specific position of the model and into a specific direction, visualized by the smoke. Even more complex is the additional consideration of a certain daytime.

Furthermore, by means of a vacuum cleaner, dynamically induced air currents can be generated. Combined with an air tube, suction or pump effects due to divergence or convergence (as reason for dynamically induced high or low pressure areas and the resulting ascending or descending airstreams) can be visualized. In addition, orographically enforced ascent of air masses can also be illustrated (see Volz & Siegmund 2015).

Thermally induced, dynamically induced and orographically enforced airstreams may appear to be the same process but have disparate causes. Since the model allows for the simulation of all three causes, it can help to enhance students' systems thinking in this area.

FIRST RESULTS OF A COMPARATIVE STUDY ON DIFFERENT MODEL APPROACHES

To what extent and how do different versions of models help to enhance pupils' geographical systems thinking? Taking the example of soil erosion, both sandbox-model and computer simulation allow for model manipulation, but differ in the degree of abstractness. An on-going study (PhD research Brockmüller) investigates which model version helps pupils to improve geographical systems thinking most effectively. Differences in systems thinking between three groups of pupils working with different model versions are compared. During the intervention, the pupils record, analyse and evaluate the complex influencing factors on soil erosion by means of

(1) hands-on experiments (based on irrigated reference soil boxes - as shown in Figure 3),

(2) abstract computer simulations (based on mathematical soil loss equations), and

(3) a combination of both approaches.

Pre-post comparison is meant to show which approach helps pupils to understand selected aspects of geographical systems most effectively and whether that is dependent on learning style. The developed test contains 12 items which are assigned to four different dimensions of system competency such as (a) declarative/conceptual system knowledge, (b) ability of system modelling, (c) ability of using system modelling for problem solving, (d) evaluating system modelling results (Bräutigam 2014, Rieß et al. 2015).

A pilot study with n=78 showed the following results: First item analysis (EFA in R) indicates two factors/principal axes, second analysis (CFA in R) confirms one factor with eight items concerning specific content related system thinking (Cronbachs α of 0,73) and another factor with four items concerning general theoretical systems thinking (Cronbachs α of 0,69). The group-comparison by means of a one-way analysis of variance (Tucey HSD test in SPSS) reveals the following first results: In both pre- and post-test there are no significant group differences between groups (1), (2) and (3). Due to a very low effect size of $\eta^2 = 0.023$ a higher number of test participants is needed to reveal possible differences.

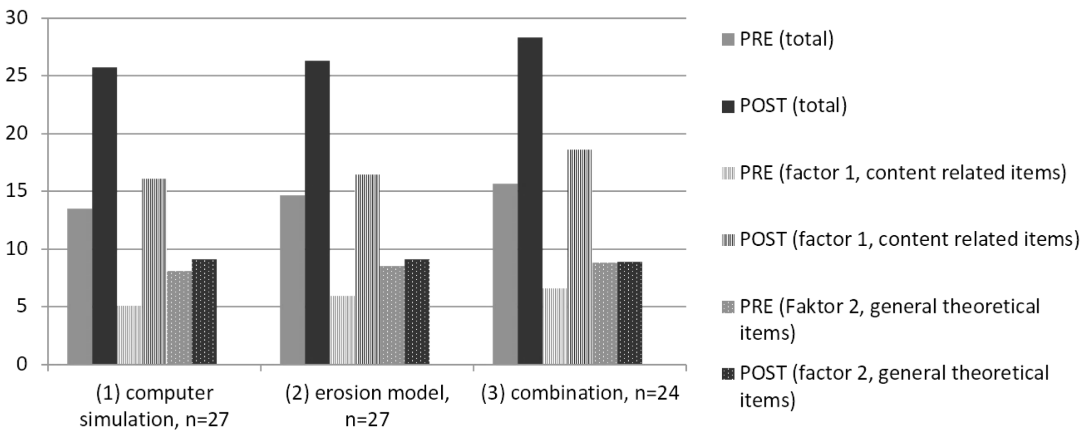

Figure 5: Mean differences between pre- and post-test.

The within-group comparison of pre- and post-test means (via T-test in SPSS) shows significant improvement for all three test groups (computer simulation, erosion model and combination) regarding the total amount of all test items. A separate analysis of the items of factor 1, specific content related systems thinking, and of factor 2, general theoretical systems thinking, shows significant mean differences only for the factor 1-items (see Figure 5). Figure 5 also shows that group 3 (combination) has both the best pre-score mean and the largest pre-post-test difference.

As an interim conclusion, both soil erosion models and computer simulations seem suitable for the content related enhancement of systems thinking skills. All three test groups were able to benefit significantly from the intervention. The “combined group”, which used hands-on erosion models as well as computer simulations, achieved the best overall result however there are not as yet significant differences identifiable.

DESIGN CRITERIA FOR TEACHING WITH GEOGRAPHICAL MODELS

Certain "tools" (e.g. flow diagrams, concept maps, behaviour over time graphs, etc.) are stated to help pupils and students to understand systems (e.g. Frischknecht-Tobler et al. 2008, Ossimitz 2000). In our view, manipulable geographical models are an additional tool that could help pupils to improve their systems thinking skills. Based on literature and a range of practical experiences in using widely varied models in geography education from primary school to university, we have derived preliminary design criteria. These can be divided into (1) general model criteria and (2) criteria specific to enhancing systems thinking, and need to be tested empirically (see Table 2).

Table 2. Design criteria of geographical models.

PROPOSED DESIGN CRITERIA OF (GEOGRAPHICAL) MODELS		
Category	**(1) General model criteria**	**(2) Specific model criteria for enhancing systems thinking**
(a) Model construction	• Transportability • Affordable, easy to acquire and re-usable models/model components • Ease of cleaning and putting away the model • Versatility • Size as small as possible, as big as necessary • Little or no possibilities for pupils to get hurt • No distractions • Stable and repairable	• Manipulation of individual system parameters, independently from each other • Simulation of sudden events and feedback loops • Possibility to compare the results of different model runs • Differences quantifiable if possible • Close to reality/abstract models allow for inductive/deductive reasoning • Models represent human-environment relationships if relevant
(b) Model application	• Visibility of relevant processes • Not contributing to misconceptions • As few "didactic tricks" (such as battery drive, etc.) as possible, as hidden as possible	• Age appropriate reduction of systems to their key parameters without causing misconceptions • All substantial system components, processes and relationships are included • Model is possibly causing cognitive conflicts • Problem-based application of the model possible
(c) Model instruction	• Target group adequacy (e.g. opportunities of dealing with diversity) • Clear instruction • Safety regulations	• Instruction explicitly pointing the pupils' attention to the parameters and the interactions between them • Instruction focuses on the distinction of natural and anthropogenic influencing factors and on the effects of different interferences if relevant • Enables both scaffolded and free exploration • Discussion about pupils' concepts is encouraged

PERSPECTIVE

Despite the advanced state of research concerning models (see e.g. Upmeier zu Belzen & Krüger 2010 for biology education) and the fact that system understanding has been a main goal of geography education for a long time, there are only few empirical studies examining in what way or to what extent models help reaching this goal. Our paper discusses some facets of the potential of geographical models to enhance systems thinking based on various projects that are underway at the Heidelberg University of Education, but more research is needed.

REFERENCES

Birkenhauer, J. (1997). Modelle im Geographieunterricht [Models in geography education]. *Praxis Geographie 27*(1), 4-8.

Brandt, C., Brockmüller, S., Volz, D. & Siegmund, A. (2015). Wenn der Wald in „Stress" gerät. Das Anpassungspotenzial heimischer Wälder an den Klimawandel bewerten [When the forest gets stressed. Evaluating native forests' potential to adapt to climate change]. *geographie heute 322*, 32-37.

Bräutigam, J. I. (2014). *Systemisches Denken im Kontext einer Bildung für nachhaltige Entwicklung. Konstruktion und Validierung eines Messinstrumens zur Evaluation einer Unterrichtseinheit* [Systemic thinking in the context of education for sustainable development. Construction and validation of a measurement instrument for evaluating a lesson unit] (Doctoral dissertation). Retrieved from phfr.bsz-bw.de/files/412/DissertationBraeutigamJulia2014.pdf

Brockmüller, S. & Jungkunst, H. F. (2015): Was tun, wenn der Boden sich vom Acker macht?! Einflussfaktoren erkennen und verstehen, Schutzstrategien beurteilen [What to do when the soil gets lost?! Recognizing and understanding influencing factors, evaluating protection measures]. *Praxis Geographie 45* (5), 36-41.

Brockmüller, S., Brandt, C. & Siegmund, A. (2015). Beobachten im Gelände, Analysieren im Labor, vereinfachend Veranschaulichen im Experiment und Modell - Untersuchungen zur Kompetenzförderung im Rahmen eines methodisch-didaktischen Dreiklangs [Observing in the field, analyzing in the laboratory, illustrating in a simplified manner in experiment and model – Studies regarding competency enhancement in the framework of a methodological-didactical triad]. *Abstractband HGD-Symposium, 26.-28.03.2015 in Bochum*, 27-30.

Brockmüller, S., Schuler, C., Volz, D. & Siegmund, A. (2016). Outdoor Education an unterschiedlichen außerschulischen Lernorttypen – Klimawandel im Gelände, Labor, Experiment und Modell erfahrbar machen [Outdoor Education at different out-of-school learning places – Climate change as tangible experience in the field, in the laboratory and by means of experiments and models]. In von Au, J., Gade, U. (Eds.)*, "Raus aus dem Klassenzimmer", Outdoor Education als Unterrichtskonzept*, (pp. 119-128). Weinheim, Basel: Beltz.

DGfG (2012). *Bildungsstandards im Fach Geographie für den Mittleren Schulabschluss mit Aufgabenbeispielen* [Educational standards in the subject geography for the intermediate school certificate with sample tasks]. Bonn: Selbstverlag Deutsche Gesellschaft für Geographie.

Frischknecht-Tobler, U., Kunz, P. & Nagel, U. (2008). Systemdenken – Begriffe, Konzepte, Definitionen [System thinking – Terms, concepts, definitions]. In Frischknecht-Tobler, U., Nagel, U. & Seybold, H. (Eds.), *Systemdenken. Wie Kinder und Jugendliche komplexe Systeme verstehen lernen* (pp. 11-31). Zürich: Pestalozzianum.

Hoffmann, K.-W., Dickel, M., Gryl, I. & Hemmer, M. (2012). Bildung und Unterricht im Fokus der Kompetenzorientierung – Aktuelle Anfragen an die Geographiedidaktik

[Education and lessons in the focus oft he competence orientation – current inquiries to geography didactics]. *Geographie und Schule 34*(195), 4-13.

KMK (2004). *Bildungsstandards im Fach Physik für den Mittleren Bildungsabschluss* [Educational standards in the subject physics fort he intermediate school certificate]. München: Wolters Kluwer.

KMK (2005). *Bildungsstandards im Fach Biologie für den Mittleren Schulabschluss* [Educational standards in the subject biology fort he intermediate school certificate]. München: Luchterhand.

Mehren, R., Ulrich-Riedhammer, E.-M., Rempfler, A., Buchholz, J. & Hartig, J. (2015). Wie lässt sich Systemdenken messen? Darstellung eines empirisch validierten Kompetenzmodells zur Erfassung geographischer Systemkompetenz [How can system thinking be measured? Description of an empirically validated competency model for measuring geographic system competency]. *Geographie aktuell und Schule 37*(215), 4-15.

Ossimitz, G. (2000). *Entwicklung systemischen Denkens* [Development of systemic thinking]. Wien: Profil.

Rempfler, A. & R. Uphues (2012). System competence in geography education. Development of competence models, diagnosing pupils' achievement. *European Journal of Geography 3*(1), 6-22.

Rieß, W., Schuler, S. & Hörsch, C. (2015). Wie lässt sich systemisches Denken vermitteln und fördern? Theoretische Grundlagen und praktische Umsetzung am Beispiel eines Seminars für Lehramtsstudierende [How can systemic thinking be taught and enhanced? Theoretical foundations and practical implementation using the example of a course for pre-service teacher students]. *Geographie aktuell & Schule 37*(215), 16-29.

Schubert, J. C. (2013). Modelle [Models]. In Böhn, D. & Obermaier, G. (Eds.), *Wörterbuch der Geographiedidaktik. Begriffe von A-Z* (pp. 199-200). Braunschweig: Westermann.

Upmeier zu Belzen, A. & Krüger, D. (2010). Modellkompetenz im Biologieunterricht [Model competence in biology education]. *Zeitschrift für Didaktik der Naturwissenschaften 16*, 41-57.

Viehrig, K., Siegmund, A., Funke, J., Wüstenberg, S. & Greiff, S. (in press). The Heidelberg inventory of geographic system competency model. In Leutner, D., Fleischer, J., Grünkorn, J., Klieme, E. (Eds.), *Competence Assessment in Education: Research, Models and Instruments*. Series: Methodology of Educational Measurement and Assessment. Springer.

Volz, D. & Siegmund, A. (2015). Förderung systemischen Denkens durch den Einsatz experimenteller Arbeitsweisen – Eine Interventionsstudie bei Lehramtsstudierenden im Bereich Physische Geographie [Enhancing systemic thinking through using experimental approaches – An intervention study with pre-service teacher students in the area of physical geography]. *Abstractband HGD-Symposium, 26.-28.03.2015 in Bochum*, 34-35.

Volz, D., Schuler, C., Brockmüller, S. & Siegmund, A. (in press). Beobachten, Untersuchen, Experimentieren – Ein methodisch-didaktisches Konzept zum Thema „Ökosystem Wald im Klimawandel" [Observation, Examination, Experimentation – a methodical-didactical concept on "forest ecosystem in climate change"]. *Geographie aktuell & Schule, 37*(219).

Wiktorin, D. (2013). Graphische Modelle im Geographieunterricht. Handlungsorientierter Einsatz von und kritischer Umgang mit Modellen [Graphical models in geography education. Action-based use of and critical handling of models]. *Praxis Geographie 43*(12), 4-7.

Wirth, E. (1979). *Theoretische Geographie* [Theoretic geography]. Wiesbaden: Teubner.

STUDENTS' DIFFICULTIES IN UNDERSTANDING THE BASIC PRINCIPLES OF RELATIVITY AFTER STANDARD INSTRUCTION

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Abstract: Theory of Relativity (Special and General) is one of the most influential theories of the 20th century and has changed the way we view the world. It is part of many undergraduate curriculums and it is often suggested that it should be integrated into an upper secondary curriculum. Special Theory of Relativity combines time and space whereas General Theory of Relativity describes gravity as a geometric property of spacetime. As it describes abstract phenomena, students encounter several difficulties understanding its basic principles and consequences. In this paper, we present the research that we conducted in order to detect the aforementioned difficulties. This research constitutes a part of a more general study concerning the integration of Special and General Relativity into an upper secondary and undergraduate curriculum. The sample consisted of 45 non-major physics undergraduate students. The purpose of our study was to determine and categorize the difficulties students face when they study the principles of the Theory of Relativity and its consequences. The results of our research indicate that student face many obstacles when trying to interpret phenomena described by the Relativity and confuse Special and General Relativity principles. These results dictate us to create an educational approach that tackle the difficulties found.

Keywords: Special Relativity, General Relativity, students' difficulties, qualitative study

INTRODUCTION

Theory of Relativity is one of the most influential theories of the 20th century that change the way we view the physical world. It is part of many undergraduate curriculums and it is often suggested that it should be integrated into an upper secondary curriculum (Arriassecq & Greca, 2010; Villani & Arruda, 1998). The failure of experiments to detect any motion of ether led to Einstein's two basic postulates of Special Relativity and their consequences (relativity of simultaneity, time dilation and length contraction). While Special theory of Relativity is primarily concerned with inertial frames of reference, accelerated frames of reference and gravity are treated in General Relativity, as table 1 presents. Relativity has, also, many applications with GPS being one of the most known among them. As the phenomena Relativity describes can be characterized as abstract, researching students' difficulties in understanding these phenomena is of great interest for the educational community.

Table 1.
The Theory of Relativity

Theory of Relativity	
Special Relativity	General Relativity
Basic Postulates	Basic Postulate
Invariance of Physical Laws Invariance of the speed of light	Principle of Equivalence
Applications	Applications
Relativity of Simultaneity Time Dilation Length Contraction	Bending of light Modification of time by gravitational fields

Reasons why we should teach relativity and conduct research on how best to include it in current curriculum

Relativity constitutes a revolutionary & influential Theory, it is part of many undergraduate curriculums and many researchers and educators suggest that it should be integrated into an upper secondary curriculum. It is part of our cultural heritage and describes as well as interprets abstract phenomena. Moreover, it provokes students' excitement and develops abstract way of thinking. So, researching students' difficulties in understanding these phenomena is of great interest for the educational community.

LITERATURE REVIEW

Defining the term "Difficulties in understanding"

According to Centeno (1988) difficulty is something that constrains students' understanding of a given subject. Some of students' ideas correctly interpret particular phenomena, but fail to do so in other phenomena (more general most of the time). According to Brousseau (1983) , difficulty is knowledge, not necessarily lack of it. In addition to this, students often ignore the existence of a wrong knowledge and as a result they find it difficult to replace it with the scientifically correct one.

Educational Research in Relativity

There is a small number of studies concerning the difficulties students face when they study the Theory of Relativity (Pitts,Venville, Blair & Zadnik, 2014) the results of which are summarized in the following points:

a) Students find it difficult to define and thus describe a Frame of Reference and they believe in the existence of a privileged observer (Arriasecq I. & Greca M.I. 2010; Scherr et al 2001; Panse et al 1994 ;Ramadas et al 1996; Villani & Pacca, 1987).

b) Many students predict the progress of a physical phenomenon, without using the principle of relativity. Moreover, they cannot apply the invariance of the speed of light (Pietrocola & Zylbersztajn,1999; Scherr et al 2001;Dimitriadi & Halkia, 2012).

c) Students cannot perceive that two simultaneous events in a particular Frame of Reference are not necessarily simultaneous relative to another Inertial Frame of Reference. What is more, they hold the view that time is absolute and that both time dilation and length contraction constitute a distortion of the reality (Scherr 2007, Scherr et al 2001; Hewson 1982 , Posner et al 1982).

d) Students use Special Relativity postulates so as to interpret phenomena of General Relativity (Bandyopadhyay,A., Kumar, A., 2010).

RESEARCH QUESTION

Aiming to contribute to the aforementioned literature we designed our research and developed our research question.

"Which are non-major physics students' difficulties in understanding the basic principles of the Theory of Relativity and its consequences after standard instruction?"

METHOD

In order to measure the difficulties, we constructed a questionnaire that included open ended questions and was based on the existing literature. In addition to questionnaire (Figure 1), we conducted interviews so as to go deeper and get a better picture of students' difficulties. The research was conducted in two phases:
In the first phase we conducted a pilot study with 10 non major physics undergraduate students as our sample. Our tool was a questionnaire that included open ended questions and was revised by 2 experts in physics and 2 experts in educational research.

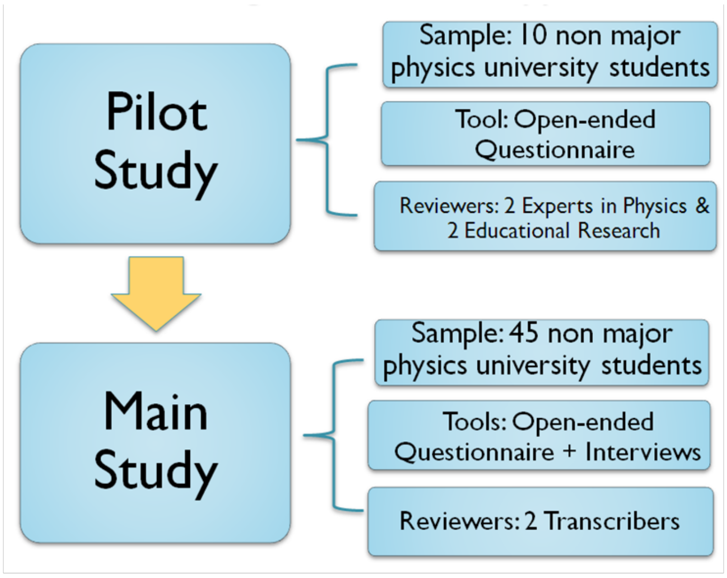

Figure 1. **Research Design – Qualitative Approach**

The next phase included the main study with a sample of 45 non major physics undergraduate students of the Pedagogical Department at the University of Athens. As our main tool we used the aforementioned questionnaire that that was amended so as to incorporate students' feedback from the pilot study. In addition to this questionnaire we conducted interviews with 10 students so as to get a deeper understanding of their difficulties and test our assumptions. Finally, aiming to assure the reliability of our study, we had 2 transcribers to analyze the data collected.
Students that comprised the sample of our main study attended a series of lessons, the structure of which is shown at Table 2.

Table 2.
Regular Instruction Scheme

Lesson Unit	Instructional Time Interval
Kinematics & Dynamics Review	2 x 45 min.
Inertial Frame of References	2 x 45 min.
Basic Principles of the Special Theory of Relativity	2 x 45 min.
Relativity of Simultaneity, Time Dilation, Length Contraction	3 x 45 min.
Principle of Equivalence	2 x 45 min.
Bending of light	45 min.
Modification of time by gravitational fields	45 min.

The aforementioned Instructional Scheme is based on the newly introduced Greek Curriculum.
Our tools examined the following thematic units:
a) Principle of Relativity, b) Invariance of the speed of light, c) Relativity of Simultaneity, d) Time Dilation, e) Length Contraction, f) Principle of Equivalence, h) Bending of light and i) Modification of time by gravitational fields.
After analyzing the data collected using qualitative approaches, we categorized our findings based on the above mentioned thematic units.

RESULTS

Einstein's Principle of Relativity - invariance of physical laws

Some students (40%) found it difficult to perceive the equivalence between motionless and uniform motion. They said that phenomena (either electromagnetic or mechanical) can progress differently for different observers. For instance, they believe that an object moving at a constant speed relative to an observer O can accelerate or decelerate relative to a different inertial observer O΄.

Invariance of the speed of light

Many students (66,7%) stated correctly the invariance of the speed of light, but they failed to apply it in problems in which the speed of light was demanded. Instead they used the Galilean velocity addition formula.

Relativity of Simultaneity

Some students (24,4%) considered that two events that are simultaneous for an observer, must be simultaneous for any other inertial observer.
"Since the 2 explosions occur simultaneously for observer A, they are simultaneous for any other inertial observer".

Time Dilation

A common view among students (77,7%) was that time is absolute and unaffected by the inertial observer relative to whom it is measured.
"Time is what it is, it can't change".

Length Contraction

Students (15,5%) held the view that length is the object's inherent characteristic, thus it cannot change. They, also, related the object's length to its mass. They said that as mass cannot differentiate, nor can its dimensions.
"Since mass don't change, length stays the same"
Even though some students (71,1%) predicted correctly the length contraction, the reasons they projected were wrong. The contraction was attributed to the high speed.
"The spaceship is moving so fast that it seems smaller"
Finally, some students (55,5%) while predicting correctly the length contraction, they said that this contraction occurs in every direction of the object's motion
"…the object's length has been shortened, as it moves at x axis; likewise, there would be a length contraction if the object moved *at y axis"*

Shift in the inertial observer

Students (44,4%) found it difficult to extract correct conclusions when the inertial observer, to whom a relativistic phenomenon takes place, changes. Many students replied correctly when the phenomenon they examined took place at a Frame of Reference that is motionless relative to the observer. Yet, when the phenomenon took place at a Frame of Reference that moved uniformly relative to the observer, wrong answers rose sharply

Boundaries between classical Mechanics and Relativity

A prevailed view among students (73,3%) was that Relativity deals with phenomena that occur at relativistic speeds or due to large amounts of mass.
"Theory of relativity concerns phenomena that take place only at speeds near the speed of light".

Principle of Equivalence

While applying correctly the Principle of Equivalence outside a gravitational field, students (64,4%) failed to do the same in areas inside a gravitational field.
"If I accelerate a box towards the earth at amount equal to g, the people inside the box will feel doubled acceleration. We should accelerate the box by g at the opposite direction so that they can feel zero gravity".

Bending of light

Classical Physics was deeply rooted into students' mind (57,7%). There were cases where they changed a correct answer due to the aforementioned obstacle.
"Light can't follow a curved path. The right lines are those that I haven't erased"(Figure 2).
Moreover, bending of light was being attributed to the existence of an invisible mirror (51,1%).
"There should be a mirror so as to make the light to curve"

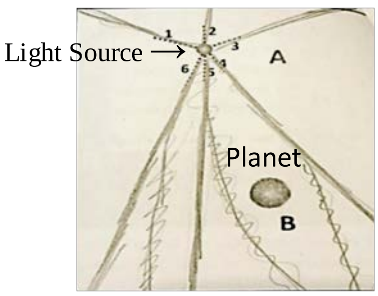

Figure 2. **Student's drawing concerning the bending of light**

Modification of time by gravitational fields

There was a confusion between General and Special Relativity regarding the rate of time flow inside a gravitational field (37,8%).
"Since a satellite has a velocity at this height, there is a time dilation; is there any possibility to have a time modification due to both theories?"

DISCUSSION

Returning to our research question, we found that non-major physics students encounter various difficulties after regular instructional series. In general, most of our findings go along with the corresponding findings of the international literature. More specifically, students find it difficult to understand the invariance of physical laws confirming the results of Pietrocola & Zylbersztajn (1999). Moreover, students use the Galilean velocity addition formula so as to answer question regarding the invariance of the speed of light ignoring the invariance of the speed of light (Scherr et al 2001). As far as the consequences of Special Relativity are concerned, students face several difficulties understanding them. For instance, students stated that two events that are simultaneous for an observer must be simultaneous for any other inertial observer (Scherr et al 2001). Furthermore, students project the idea that time and space are absolute and unaffected by the inertial observer (Dimitriadi & Halkia, 2012; Posner et al 1982). An interesting aspect of our findings is that, the contraction was attributed to the high speed and even though some students predicted correctly the length contraction, they said that this contraction occurs in every direction of the object's motion. What is more, students found it difficult to extract correct conclusions when the inertial observer, to whom a relativistic phenomenon takes place, changes. Our research has, also, unveiled difficulties concerning the General Relativity. Students fail to apply correctly the principle of equivalence inside a gravitational field and attributed the bending of light to the existence of an invisible mirror. Moreover, among students there was confusion between General and Special Relativity regarding the rate of time flow inside a gravitational field. Finally, one finding that should be underlined is the view that Relativity deals with phenomena that occur at relativistic speeds or due to large amounts of mass constraining students understanding regarding the boundaries between classical Mechanics and Relativity. The aforementioned findings of our research combined with the relevant international literature should be taken into account when a country's educational committee intends to build a curriculum that includes topics from the Relativity. Acknowledging students' difficulties in understanding the basic elements of the theory of relativity, leads to the construction of an effective educational approach.
An interesting expand of our study would be the application of our tool to students coming from the upper secondary education, as well as from physics departments.
To conclude, an educational approach should be created aiming to cope with the difficulties found. Our proposal, which will be our next step, is an educational approach using interactive dynamic simulations in order to visualize relativistic phenomena that exists outside our everyday experience.

REFERENCES

Arriassecq, I., & Greca, I. M. (2012). A teaching–learning sequence for the special relativity theory at high school level historically and epistemologically contextualized. *Science & Education*, 21(6), 827-851.

Bandyopadhyay, A., Kumar, A., (2010). Probing students' understanding of some conceptual themes in general relativity. *Physical Review Special Topics-Physics Education Research*, 6(2), 020104.

Brousseau, G. (1983). Les obstacles epistémologiques et les problémes en mathématiques. *Recherches en Didactique des Mathématiques*, 4 (2), 164-198.

Centeno, J. (1988). *Numeros decimates ¿por que? ¿.para que?*. Madrid: Sintesis.

Dimitriadi, K., & Halkia, K. (2012). Secondary students' understanding of basic ideas of special relativity. *International Journal of Science Education*, 34(16), 2565-2582.

Hewson, P. W. (1982). A Case Study of Conceptual Change in Special Relativity: The Influence of Prior Knowledge in Learning. *European Journal of Science Education*, 4(1), 61-78.

Panse, S., Ramadas, J., & Kumar, A. (1994). Alternative conceptions in Galilean relativity: frames of reference. *International Journal of Science Education*, 16(1), 63-82.

Pietrocola, M., & Zylbersztajn, A. (1999). The use of the Principle of Relativity in the interpretation of phenomena by undergraduate physics students.International *Journal of Science Education*, 21(3), 261-276.

Pitts, M., Venville, G., Blair, D., & Zadnik, M. (2014). An Exploratory Study to Investigate the Impact of an Enrichment Program on Aspects of Einsteinian Physics on Year 6 Students. *Research in Science Education*, 44(3), 363-388.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science education*, 66(2), 211-227.

Ramadas, J., Barve, S., & Kumar, A. (1996). Alternative conceptions in Galilean relativity: inertial and non-inertial observers. *International journal of science education*, 18(5), 615-629.

Scherr, R. E. (2007). Modeling student thinking: An example from special relativity. *American Journal of Physics*, 75(3), 272-280.

Scherr, R. E., Shaffer, P. S., & Vokos, S. (2001). Student understanding of time in special relativity: Simultaneity and reference frames. *American Journal of Physics*, 69(S24- S1), S35.

Villani, A., & Arruda, S. M. (1998). Special theory of relativity, conceptual change and history of science. *Science & Education*, 7(1), 85-100.

Villani, A., & Pacca, J. L. D. A. (1987). Students' spontaneous ideas about the speed of light. *International Journal of Science Education*, *9*(1), 55-66.

INVESTIGATING STUDENTS' CONCEPTUAL UNDERSTANDING THROUGH SOLVING KINEMATICS PROBLEMS IN VARIOUS CONTEXTS

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Abstract: Students' perceptions of the nature of physics knowledge affect their understanding of physics and the relevancy they attribute to concepts and principles to explain phenomena and solve problems to make sense of the natural world. Conceptual understanding of mechanics and the basic Newtonian concepts provides the foundation on which more advanced physics and engineering courses are built. It is crucial that students develop sufficient conceptual understanding of physics concepts to enable them to explain daily events from a scientific point of view and implement physics knowledge as a coherent web of ideas which applies to all walks of life. However, research reports deficiencies in students' conceptual understanding and ability to apply physics knowledge in unfamiliar contexts, even after tertiary education is completed. In this study we investigate the extent to which directions and planes of motion as different contexts in problem settings influence students' reasoning on idealized theoretical linear motion, and the implications of such influence. A multiple-choice questionnaire consisting of isomorphic problem pairs with the same underlying principle but set in different contexts, was designed and was completed by 481 university students in a first-year physics course on Newtonian mechanics. The questionnaire was followed by interviews with four randomly selected students. The results show that the direction and/or plane of motion affects the knowledge framework students invoke when they solve problems on idealized theoretical linear motion. The difficulty posed by conditions such as 'in the absence of air resistance and friction is illuminated. This study provides insight into what students perceive as different contexts and also shows, for the first time, that the challenges posed by context can be used to effectively evaluate conceptual understanding of the net force–mass–acceleration relationship as defined in Newton's second law of motion.

Keywords: conceptual understanding, context, direction of motion

INTRODUCTION AND PROBLEM STATEMENT

Despite having a substantial body of empirical research on students' conceptions, mechanics remains a difficult domain to teach and to learn (Duit, Schecker, Höttecke & Niedderer, 2014). Students' ability to generalize principles to various situations and develop a working knowledge of basic concepts in mechanics is an important goal in physics education. Conceptual understanding of and the ability to apply the basic Newtonian concepts in introductory mechanics courses is essential for laying the foundation for advanced physics and engineering courses (Hedge & Meera, 2012). Even though physics is based on only a few concepts many students fail to see physics knowledge as a coherent structure (Singh, 2007). Students' misconceptions about the nature of science—e.g. the belief that science comprises of incontrovertible absolute truths as opposed to scientific knowledge that is subject to change and involves the invention of explanations, contribute to their difficulty to apply concepts and principles to explain phenomena and solve problems to make sense of the natural world (Ledermann & Ledermann, 2014). When students understand physics concepts, they are able to solve problems and, when they see physics knowledge as a coherent web of ideas which applies to all walks of life, they can predict and explain various phenomena scientifically (Muis & Gierus, 2014; Ogilvie, 2009). Despite the recognized importance of the development of conceptual understanding, research in physics education shows that only few students are able to explain daily events from a scientific point of view, even after completing standard mechanics courses successfully.

THEORETICAL FRAMEWORK

Students’ epistemologies (i.e. their perceptions of the nature of science and the nature of physics knowledge in particular) may affect their understanding of physics (Duit et al., 2014; Hammer & Elby, 2003). Students’ epistemologies with such impact include the perceptions of physics as a set of disconnected facts and formulae, of formulae as expressions of interconnected concepts, and of physics learning as absorption of information (Lising & Elby, 2005). While physicists use concepts and principles to explain phenomena and solve problems to make sense of the natural world, many students try to find correct answers by plugging numerical values into equations that they often do not conceptually understand (Hutchison & Hammer, 2010). Daily life similarities in the observable features of associated phenomena usually determine intuitive mental categories. Physicists instead look for physics principles shared by phenomena that students may regard as dissimilar (Goldstein & Sakamoto, 2003).

Students’ epistemic beliefs and alternative conceptions

Every student in introductory physics has a system of beliefs about physics based on their everyday-life observations (reviews of students’ epistemologies and related research are found in Duit et al., 2014; Ledermann & Ledermann, 2014). Disagreement between these beliefs (experiential knowledge) and the formal scientific explanations often results in students’ distorted comprehension of physics concepts. These distortions are among the principle causes of students' failure to achieve understanding in science (two extensive reviews of this and related research are found in Driver and Erickson, 1983; Gilbert and Watts, 1983). For example, many students correctly answer that in free fall objects of different mass will fall at the same rate, but when they have to apply the same concept (i.e. free fall) for the objects projected upward, they are unable to do so correctly. Even when students believe that they are learning about the real world when they study physics, failing to connect physics to their daily lives may result in their perception that the physics concepts have little relevance to their personal experience (Von Aufschnaiter & Rogge, 2015).

While physics phenomena are idealized, or cleaned of distracting factors when introduced to high school or undergraduate students, real-world phenomena are influenced by multiple and complex parameters which often require advanced mathematics for prediction or measurement of those phenomena (Duit et al., 2014). The high degree of mathematization, failure to specify what counts as explanations and the lack of clarification of what theoretical perspectives comprise, contribute to students’ perception that physics is difficult. Contextual or ‘everyday’ physics problems are almost always simplified by cleaning it of elements such as friction or air resistance. Although disregarding such real-world factors in physics problems allows the use of physics equations involving uncomplicated mathematics, without sufficient clarification, the idealized scientific concept conflicts with students’ experiential knowledge. Students consequently believe that the underlying principle does not occur naturally in the everyday world, nor is it relevant to their daily lives (Gunstone, 1987).

Evaluating conceptual understanding

The reported context dependence of students’ epistemic beliefs, highlights the fundamental role that context plays in the physics learning process (Muis & Gierus, 2014; Gunstone & White, 1981). Students’ lack of conceptual coherence of physics and their poor performance on contextual problems indicate conventional instruction’s failure to identify or address ineffective tuition practices (Osborne, 2013; Von Aufschnaiter & Rogge, 2015). Such findings of research shows the need to develop tools that differentiate between students' conceptual knowledge and conceptual understanding (Rebello & Rebello, 2011).

A way to evaluate concept development is to compare various similar situations (isomorphic situations) including situations in which students will likely fall back on their naïve knowledge while applying the same concept (Minstrell, 1982). Using isomorphic situations in research brings out the nature of student beliefs, reveals the existence of student misconceptions — or alternative conceptions — and clarifies the reasoning behind those misconceptions (Singh, 2007).

Direction and plane of motion

Information on the influence of the direction or plane of motion as separate contexts in student applications of kinematics concepts is limited. An extensive literature search found no research that statistically compared inclined plane motion, vertical motion in opposite directions and horizontal motion. Research on students' applications of alternative conceptions of force–acceleration–motion relationships, however, revealed that the direction and plane of motion play a role in student reasoning (Palmer, 1997, 2001; Lemmer, 2013). Palmer (2001) reported on students' perception that gravity acts on objects moving vertically downwards but not on objects projected vertically upwards. This supported his earlier report (1997) that students associate the direction of motion with the direction of the force. The earlier results (1997) indicated that the effect of a force opposing motion was applied more correctly in horizontal than in vertical motion. Lemmer (2013) presented evidence that student reasoning differed for motion in horizontal versus vertical downward plane, but were consistent for motion up and – down an inclined plane.

We conducted this study to investigate the effect of direction and plane of motion as contextual factors on idealized everyday- and formal physics problems. We show how some difficulties regarding conceptual understanding and factors influencing students' abilities to apply physics concepts in different contexts, can be implemented to enhance tuition.

Research questions

The main question this research attempted to answer was: To what extent are first-year university physics students able to apply formal conceptual reasoning to theoretical idealized situations set in different contexts? The following secondary questions were asked to obtain realistic, reliable and valid answers:

(1) What information regarding students' epistemological beliefs and conceptual understanding is revealed by the changes in the direction and plane of motion in physics problems?
(2) How can the acquired information be implemented in tuition to develop formal conceptual understanding?

METHOD

Research design

The chosen methodology was an explanatory sequential mixed-method design. The quantitative phase was completed by 418 students enrolled for first-year physics at a university in South Africa. The sample represented students from the calculus-based and non-calculus-based physics modules, as well as both genders. The number of students enrolled for the different modules is presented in Table 1. For the qualitative phase of the study four randomly selected students were interviewed individually in semi-structured interviews.

Data collection and processing

The research instrument for the quantitative phase was a multiple-choice questionnaire consisting of theoretical, idealized isomorphic problem pairs testing for the same underlying concept. The concept of free fall in idealized contexts — i.e. in the absence of air resistance and friction all objects have equal acceleration regardless of their mass — was the underlying concept in the questions on which this paper reports. The motion of two objects of unequal mass released at the same time and travelling the same distances, had to be considered. The motion had to be compared either in terms of the time the objects took to reach their destination or in terms of their final or initial velocities. The questionnaire comprised 21 problems. The four example problems discussed in this paper were all set in a formal conceptual context, but with different planes or directions of motion (Refer to Table 2). Student responses to questions 1 and 2 —settings with which the students were most familiar — were compared to their responses to questions in which the direction or the plane of motion was changed. The questionnaire was mostly self-complied with question 1 adapted from the Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992) and question 4 adapted from the The Energy and Momentum Concepts Survey (Singh & Rosengrant, 2003). All the problems had an option which indicated the alternative conception that heavy objects fall faster. The percentages of correct as well as alternative answers are also presented in Table 2.

The inferential statistics for the questionnaire were obtained by using SPSS Statistics Version 22, Release 22.0.0. Cronbach's Alpha and the mean inter-item correlation were calculated to indicate the reliability of the research instrument. Two-way frequency tables of paired problems were used to determine the McNemar test statistic — effect size — and phi-coefficient for the paired problems. The results of the test statistics of the paired problems are presented in Table 3.

Open-ended questions used during the interviews allowed verbal analysis, enabled the interviewer to probe the students for self-explanations. The interviews were videotaped, transcribed and analysed for patterns and trends in the data.

RESULTS

The Cronbach's Alpha and the mean inter-item correlations for the questionnaire were 0.726 and 0.158 respectively, both indicating satisfactory degrees of reliability.

The number of students and the modules they were enrolled for, are presented in Table 1 below.

Table 1. Number of students in different physics courses

Physics module	N	BEng	BSc
FSKS 111 calculus based	226	66	160
FSKS 113 non-calculus based	255	1	254
Total number:	481	67	414

The four illustrative problems reported on in this paper are presented in Table 2. The table shows the percentage of students who chose the correct answer of the two objects travelling the same time or having the same final/initial speed, as well as the percentage of students who selected the option that illustrated the alternative conception.

Table 2. Reported questions and percentages of answers

Two metal balls (blocks) are the same size but one weighs twice as much as the other.	**% correct**	**% alt conception**
The balls are dropped from the roof of a single story building at the same instant in time.		
Question 1: F ↓ t Which ball will reach the ground first?	84	15
Question 2: F ↓ v Which ball will reach the ground with the largest velocity?	69	25
Question 3: F ↑v The balls are projected upwards from the ground to reach the roof of a single story building at the same time. How do their initial velocities relate?	35	52
Question 4: F ↙ v The blocks slide down two identical frictionless slides of similar height. Which one has the larger speed at the bottom of the slide?	29	48

Key: F= formal conceptual question; ↓ = vertical downward motion; ↑ = vertical upward motion; ↙= motion on inclined plane; t= time; v= velocity/speed.

Table 3. Test statistics of paired-questions

Context	**Paired items**	**ω**	**phi-coefficient Φ**
F ↓ t : F ↓ v	1; 2	0.35	0.517
F ↓ t : F ↑ v	1; 3	0.65	0.118
F ↓ t : F ↙ v	1; 4	0.72	0.192
F ↓ v : F ↑ v	2; 3	0.48	0.132
F ↓ v : F ↙ v	2; 4	0.58	0.192
F ↑ v : F ↙ v	3; 4	0.10	0.222

DISCUSSION OF RESULTS

Students' epistemic beliefs and alternative conceptions

The percentages of students' selections of the different options are consistent with former research reporting the persistence of alternative (experiential) conceptions (Duit et al., 2014, Ledermann & Ledermann, 2014) in particular that heavy objects fall faster. For the three questions compared to question 1, a decline in the percentage of the correct answer concurred with an increase in the percentage of the alternative conception. This inverse relation can realistically be attributed to the difficulty students have in accepting the Newtonian principle for objects in free fall, namely acceleration equating net force/mass ratio. This attribution is founded on information obtained during the interviews that most students were uncertain whether the magnitude of the force of gravity or the gravitational acceleration was equal for all falling objects. All the interviewed students expressed the opinion at some time, that the force of gravity exerted by the earth was equal for all objects.

Simplification

Physics thinking originates from reconstructing certain aspects under theoretical perspective (Duit et al., 2014). However, the large effect sizes present evidence that students found it significantly difficult to apply formal reasoning to problems without friction and the absence of air resistance, set in upward and inclined motion. Most students did not see disregarding friction or air resistance as simplification of the problems. The remark "It is confusing if friction and air resistance have to be ignored" summed up the general belief.

Effect of direction and plane of motion

The large effect sizes (w = 0.72 for questions 1 and 4, and w = 0.58for questions 2 and 4) confirm that students used different knowledge frameworks to answer questions about vertical downward motion and motion on an inclined plane regardless of the physics variable that was considered. These effect sizes illuminate that the students' epistemological beliefs affect their conceptual understanding. From the effect sizes it is clear that motion on inclined planes revealed lack of conceptual understanding more than did motion in upward direction.

The large effect size for questions 1 and 3 (w = 0.65) suggested that students did not apply the same principle for an object moving in opposite vertical directions This suggestion was confirmed by the reasons students gave for selecting their options during the interviews, e.g. "Up and downward motion are not the same. They are not subjected to the same principles". The very small effect size of questions 3 and 4 (w = 0.10) confirmed that students' responses to questions on vertical upward and inclined plane motion did not differ much, although the moderate phi coefficient (Φ = 0.222) indicates that the students did not relate the said questions in the way they did questions 1 and 2 (Φ = 0.517). These effect sizes provide evidence for the students' intuitive (epistemological) beliefs that physics knowledge is not coherent but consists of loosely connected conceptions.

Comparison between questions where not only the direction but also the physics variable differed, questions 1 and 3, demonstrated that the combination of changing both the direction of motion and the physics variable, resulted in a larger effect size than did changing only direction of motion with the same physics variable to be considered (question 2 and 3, w = 0.48). The effect size w = 0.35 for questions 1 and 2, illustrated the moderate effect that changing only the physics variable had on students' responses, whereas the large phi coefficient for these two questions proves that similar knowledge frameworks were applied for questions concerning motion in the same direction.

CONCLUSION

We conclude by answering the research questions:

(1) What information regarding students' epistemological beliefs and conceptual understanding is revealed by the changes in the direction and plane of motion in physics problems?

This study confirms research reporting that students' epistemological beliefs regarding physics concept and phenomena are firmly rooted in their experiential knowledge and that it severely contradicts physics concepts (Duit et al., 2014). The negative influence of students' epistemological beliefs on their ability to transfer conceptual knowledge to unfamiliar situations is shown by the changes in the direction of plane of motion. Our results identify students' lack of understanding of how the complexity of natural phenomena is reduced by idealized theoretical perspectives, as a major factor contributing to their difficulty to apply concepts and principles to explain phenomena and solve problems to make sense of the natural world (Duit et al., 2014; Ledermann & Ledermann, 2014).

(2) How can the acquired information be implemented in tuition to develop formal conceptual understanding?

The results of our study offer a technique that not only reveals students' epistemological beliefs but also a surprisingly simple but effective way to determine whether students understand the concept of free fall, during tuition. By only reversing the direction of motion in questions commonly asked before instruction, existing alternative conceptions can be identified and addressed. Although students' difficulties to develop conceptual understanding and apply their formal conceptual knowledge to unfamiliar situations had been recognized ever since initial research on physics education was published, no former studies illustrated how these difficulties can be applied to aid instruction.

Finally, our study introduces a new approach: to reconsider the possibilities offered by documented difficulties in or limitations of instruction to develop conceptual understanding by turning them into guidelines for developing effective and relevant tuition tools.

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REFERENCES

Duit, R., Schecker, H., Höttecke, D. & Niedderer, H. (2014). Teaching Physics. In Ledermann, N.G & Abell, S.K (Eds.). *Handbook of Research on Science Education volume II*, 434-456. New York: Routledge.

Driver, R. & Erickson, G (1983). Theories-in-Action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science, *Studies in Science Education*, 10, 37–60.

Gilbert, J.K & Watts, D.M. (1983). Concepts, Misconceptions and alternative conceptions: Changing perspectives in science education. *Studies in Science Education*, 10, 61–98.

Goldstein, R.L. & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive psychology*, 46, 414-466.

Gunstone, R.F. (1987). Student understanding in mechanics: A large population survey. *American Journal of Physics*, 55(8):691–696. doi: 10.1119/1.15058

Gunstone, R.F. & White, R. T. (1981). Understanding of gravity. *Science Education*, 65, 291–299.

Hammer, D. & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences*, 12(1), 53-90.

Hedge, B. & Meera, B.N. (2012). How do they solve it? An insight into the learner's approach to the mechanism of physics problem solving. *Physical Review Special Topic - Physics Education Research*, 8, 010109–1–9.

Hestenes, D. & Wells, M. (1992). A mechanics baseline test. *The Physics Teacher*, 30(3), 159–166 166. http://dx.doi.org/10.1119/1.2343498

Hutchison, P. & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. *Science Education*, 94, 506-524.

Hestenes, D., Wells, M. & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher*, 30(3), 141–158. http://dx.doi.org/10.1119/1.2343497

Ledermann, N.G. & Ledermann, J.S. (2014). Research on Teaching and Learning of Nature of Science. In Ledermann, N.G & Abell, S.K (Eds.). *Handbook of Research on Science Education volume II,* 600-620. New York: Routledge.

Lemmer, M. (2013). Nature, Cause and effect of students' intuitive conceptions regarding changes in velocity. *International Journal of Science Education*, 35(2), 239–261.

Lising, L. & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics,* 73(4), 372-382.

Minstrell, J. (1982). Explaining the ''at rest'' condition of an object. *The Physics Teacher*, 20(1), 10–15, doi: 10.1119/1.2340924

Muis, K. R. & Gierus, B. (2014). Beliefs about knowledge, knowing, and learning: differences across knowledge types in physics. *The Journal of Experimental Education*, 82(3), 408–430, doi: 10.1080/00220973.2013.813371

Ogilvie, C.A. (2009). Changes in students' problem-solving strategies in a course that includes context-rich, multi-faceted problems. *Physical Review Special Topics - Physics Education Research,* 5, 1–14. doi: 10.1103/PhysRevSTPER.5.020102

Osborne, J. (2013). The 21st century challenge for science education: Assessing scientific reasoning. *Thinking Skills and Creativity,* 10, 265–279.

Palmer, D. (1997). The effect of context on students' reasoning about forces. *International Journal of Science Education*, 19(6), 681–696, doi: 10.1080/0950069970190605

Palmer, D. (2001). Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education*, 23(7), 691–706.

Rebello, C.M. & Rebello, S. (2011). Adapting a theoretical framework for characterizing students' use of equations in physics problem solving. *Physics Education Research conference,* American Institute of Physics Conference Procedure, 1413, 311–314.

Singh, C. (2007). Effect of misconception on transfer in problem solving. *Physics Education Research Conference,* L. Hsu, C. Henderson, and L. McCullough (Eds.), 169–199.

Singh, C, & Rosengrant, D. (2003). Multiple-choice test of energy and momentum concepts. *American Journal of Physics,* 71(6), 607–619.

SPSS Inc. (2013). IBM SPSS Statistics Version 22, Release 22.0.0, Copyright© IBM Corporation and its licensors. http://www-01.ibm.com/software/analytics/spss/

Von Aufschnaiter, C. & Rogge, C. (2015). Conceptual change in learning. In R. Gunstone (Ed.), *Encyclopedia of Science Education*: (pp.209–218). Dordrecht: Springer.

THE USE OF FACIAL MICRO-EXPRESSION STATE AND TREE-FOREST MODEL FOR PREDICTING CONCEPTUAL-CONFLICT BASED CONCEPTUAL CHANGE

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Abstract: Conceptual change through conceptual conflicts in science education has been well documented. There is, however, little research done on conceptual change through conceptual conflict in terms of students' facial expressions. The current proposal attempted to apply the decision tree methodology to examine the relationship between facial expressions and conceptual change when students were presented with different representations in a conceptual conflict scenario situation. We further propose a modified decision tree model, namely Tree-Forest Model (TF Model), to mine the overall information of the dataset of students' facial micro-expression states (FMES). Based on the Tree-Forest Model, the current study was able to present the overall pattern of the dataset collected from 86 high school students. The results revealed that a student would be predicted to undergo conceptual change if his/her dominant expression in the first play of the video was "Surprised", and the "Negative" expressions for the second or third play of the same video during the experiment. In contrast, when students' dominant expression in the first play of the video was "Not Surprised", "Surprised" in the first and second play of the video, or in the first and third play of the video, then we could predict that the students would not undergo conceptual change. In summary, using the Tree-Forest Model along with students' micro-expression states can predict their conceptual change status in facing conceptual conflict scientific phenomenon.

Keywords: Facial micro-expression, decision tree, conceptual conflict, surprise, Tree-Forest Model

INTRODUCTION

The current study stemmed from a larger research project regarding the relations between conceptual change through conceptual conflicts and facial micro-expression states (FMES) in a scientific scenario. From our previous studies (Chiu, Chou, Wu, & Liaw, 2014; Liaw, Chiu, & Chou, 2014) , we found that FMES changes were found when the majority of the students made incorrect predictions of the conceptual conflict phenomenon. Also, there was a low likelihood of conceptual change if there was a lack of FMES change. However, the likelihood of conceptual change doubled if the FMES change was observed. Furthermore, it was revealed that there existed a significant relationship between FMES changes and students' macro-submicroscopic understandings. That is, those with FMES changes were more likely to provide accurate macroscopic explanations of the scientific phenomenon than those without FMES changes. Based upon these findings, we have gone one step further in the exploration of the possibility of utilizing the decision tree method in predicting students' performance during learning processes.

LITERATURE REVIEW

It has been known that there are four preconditions for conceptual change, one of which is learner being dissatisfied with his/her existing conception (Posner, Strike, Hewson, & Gertzog, 1982). Thus, conceptual conflicts have been proposed as a viable way to initiate the process of conceptual change. However, research has shown that there is no guarantee that students will experience the conceptual conflicts and achieve new conceptual understanding (e.g., Scott et al., 1992). Several researchers identified the characteristics of responses when facing conceptual conflict scenario. For instance, Chinn and Brewer (1993, 1998) have eight different responses to anomalous data, namely, ignoring the data, rejecting the data, being uncertain about the validity of the data, excluding the data from the domain, holding the data in abeyance, reinterpreting the data, accepting the data and making peripheral changes to their erroneous intuitive understanding and its basis, and accepting the data and changing theory. Meanwhile, Merenluoto and Lehtinen (2004) argued that there are three different tracks that learners might take. These tracks are no-relevant perception track, illusion of understanding track, and experience of conflict track. From these studies, we argued that learners construct their knowledge through integrating new pieces of knowledge into existing knowledge framework via various channels and respond based upon one's background knowledge of specific domain knowledge.

Simultaneously, facial expressions are one of the most direct ways for people to express their thoughts. The study of Pekrun, Goetz, Titz, and Perry (2002) has shown that emotions are closely related to learning. Consequently, the current research project had combined learners' FMES and conceptual change in order to better understand the learning of science.

Therefore, the current study attempts to answer the following research questions:

1. Can the decision tree model explain the relationship between facial micro-expression state changes and conceptual change when students are faced with different representations?
2. Pursuant to the first research question, if relationships between facial expression change and conceptual change can be explained through the decision tree model, what is its criterion?

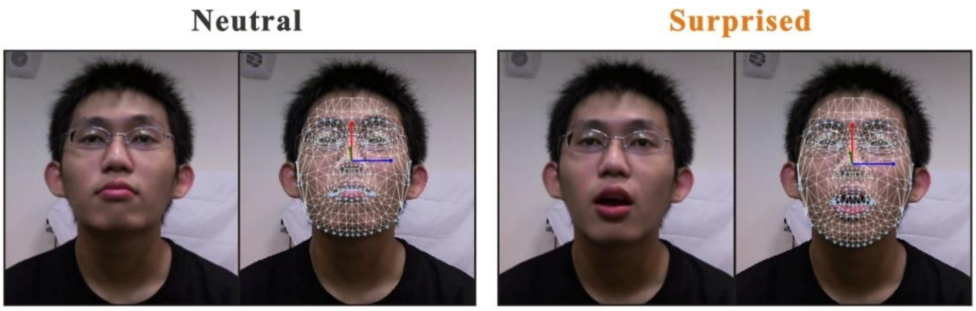
METHODOLOGY

The data was collected as part a larger research project with 86 high school student participants. The data collection process began with a pretest, after which students were given a teaching module designed based on the Predict-Observe-Explain-Visualize-Compare (details can be seen in Chiu et al., 2014; POEVC, modified from White & Gunstone, 1992) process. The topic of the scientific scenario was the relation among temperature, air pressure, and the boiling point of water. The module was consisted of a conceptual conflict inducing scientific demonstration video (i.e., placing an ice bag onto an inverted flask filled with just-boiled water, causing the water inside the flask to boil again, see Figure 1) that required the students to predict what would happen once the ice bag was placed and offer their explanations to their predictions before the result was shown. After the prediction and explanations were made, textual and animated instructions at the microscopic level were shown. A posttest then followed. Students' facial reaction and their on-screen actions throughout the process were also recorded.

Figure 1. The design of the boiling water experiment.

DATA ANALYSIS

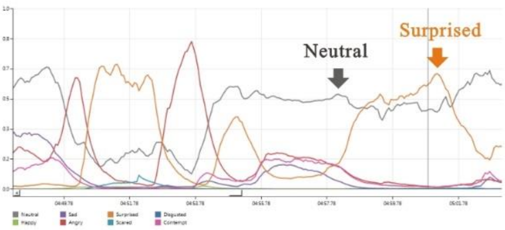
Students' facial videos were analyzed by FaceReaderTM 6.0 (See Figure 2) based on Ekman's (1970, 1993, 1999) six facial expressions and the neutral state. Each video frame was assigned a dominant FMES. Expressions were then grouped into three categories, positive, negative, and surprised for the sake of our own research interest. The current study was interested in the students' FMES when they were presented with conceptual conflict inducing scientific demonstration video. A total of five segments were analyzed: Demonstration video segment 1, segment 2 (replay), segment 3 (slow motion replay), textual instruction and animated instruction. The dominant FMES of all the frames for the duration of these segments were then tallied.



2A: Faces of Student SM009 without and with facial state change.

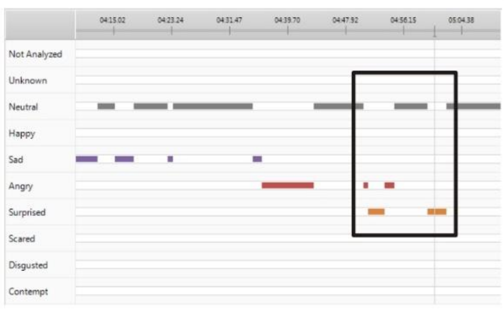
Video Time	Neutral	Happy	Sad	Angry	Surprised	Scared	Disgusted
04:58.00	5.14E-01	1.53E-03	5.36E-02	1.36E-01	1.33E-01	3.06E-04	2.74E-04
04:58.07	5.24E-01	1.57E-03	4.90E-02	1.31E-01	1.38E-01	3.30E-04	2.78E-04
04:58.13	5.26E-01	1.60E-03	4.52E-02	1.28E-01	1.43E-01	3.57E-04	2.87E-04
04:58.20	5.19E-01	1.62E-03	4.15E-02	1.21E-01	1.61E-01	3.65E-04	2.75E-04
04:58.27	5.15E-01	1.68E-03	3.58E-02	1.12E-01	1.86E-01	4.92E-04	2.96E-04
04:58.33	5.14E-01	1.82E-03	3.08E-02	1.04E-01	2.08E-01	6.93E-04	3.28E-04
04:58.40	5.09E-01	2.02E-03	2.62E-02	9.35E-02	2.46E-01	7.59E-04	3.49E-04
04:58.47	4.73E-01	2.05E-03	2.22E-02	8.48E-02	2.95E-01	8.10E-04	3.89E-04
04:58.53	4.68E-01	2.20E-03	1.88E-02	7.61E-02	3.34E-01	8.72E-04	4.20E-04
04:58.60	4.56E-01	2.28E-03	1.61E-02	6.92E-02	3.69E-01	9.54E-04	4.52E-04
04:58.67	4.50E-01	2.30E-03	1.38E-02	6.47E-02	3.86E-01	1.03E-03	4.82E-04
04:58.73	4.47E-01	2.38E-03	1.19E-02	5.92E-02	4.11E-01	1.20E-03	5.16E-04
04:58.80	4.50E-01	2.44E-03	1.03E-02	5.44E-02	4.29E-01	1.32E-03	5.45E-04
04:58.87	4.53E-01	2.52E-03	8.98E-03	5.06E-02	4.41E-01	1.55E-03	5.75E-04
04:58.93	4.50E-01	2.74E-03	7.83E-03	4.68E-02	4.57E-01	1.59E-03	5.85E-04
04:59.00	4.46E-01	2.87E-03	6.95E-03	4.41E-02	4.69E-01	1.64E-03	5.95E-04
04:59.07	4.54E-01	3.09E-03	6.14E-03	4.11E-02	4.80E-01	1.63E-03	5.88E-04
04:59.13	4.62E-01	3.25E-03	5.51E-03	3.94E-02	4.83E-01	1.71E-03	6.15E-04
04:59.20	4.58E-01	3.31E-03	5.13E-03	3.83E-02	4.86E-01	1.79E-03	6.23E-04
04:59.27	4.45E-01	3.46E-03	4.83E-03	3.62E-02	4.97E-01	1.80E-03	5.97E-04
04:59.33	4.42E-01	3.64E-03	4.48E-03	3.46E-02	5.06E-01	1.91E-03	5.97E-04
04:59.40	3.99E-01	3.67E-03	4.36E-03	3.18E-02	5.27E-01	2.62E-03	5.82E-04
04:59.47	3.83E-01	3.77E-03	4.30E-03	3.25E-02	5.13E-01	2.87E-03	6.57E-04
04:59.53	4.06E-01	3.79E-03	4.16E-03	3.90E-02	4.82E-01	2.55E-03	6.98E-04
04:59.60	4.34E-01	3.79E-03	3.81E-03	3.91E-02	4.75E-01	2.43E-03	7.20E-04
04:59.67	4.50E-01	3.74E-03	3.46E-03	3.99E-02	4.68E-01	2.54E-03	7.83E-04
04:59.73	4.34E-01	3.83E-03	3.18E-03	3.63E-02	4.98E-01	2.48E-03	7.50E-04
04:59.80	4.39E-01	3.78E-03	3.04E-03	3.54E-02	4.95E-01	2.49E-03	7.33E-04
04:59.87	4.59E-01	3.86E-03	2.88E-03	3.36E-02	4.95E-01	2.60E-03	7.21E-04
04:59.93	4.70E-01	4.00E-03	2.71E-03	3.18E-02	4.97E-01	2.83E-03	7.24E-04
05:00.00	4.64E-01	4.37E-03	2.59E-03	2.91E-02	5.15E-01	2.83E-03	6.85E-04
05:00.07	4.69E-01	4.62E-03	2.45E-03	2.75E-02	5.17E-01	3.10E-03	6.94E-04
05:00.13	4.80E-01	4.83E-03	2.36E-03	2.79E-02	5.03E-01	3.46E-03	7.27E-04
05:00.20	4.72E-01	5.36E-03	2.32E-03	2.57E-02	5.17E-01	3.38E-03	6.75E-04
05:00.27	4.75E-01	5.65E-03	2.28E-03	2.44E-02	5.19E-01	3.46E-03	6.58E-04
05:00.33	4.75E-01	5.93E-03	2.24E-03	2.27E-02	5.30E-01	3.49E-03	6.31E-04
05:00.40	4.78E-01	5.96E-03	2.23E-03	2.27E-02	5.21E-01	3.79E-03	6.54E-04
05:00.47	4.79E-01	6.06E-03	2.30E-03	2.14E-02	5.27E-01	3.57E-03	6.16E-04
05:00.53	4.81E-01	6.22E-03	2.31E-03	2.01E-02	5.37E-01	3.46E-03	5.89E-04
05:00.60	4.50E-01	6.24E-03	2.29E-03	1.87E-02	5.58E-01	3.47E-03	5.63E-04
05:00.67	4.32E-01	6.14E-03	2.21E-03	1.83E-02	5.67E-01	4.00E-03	5.84E-04
05:00.73	4.35E-01	6.08E-03	2.16E-03	1.70E-02	5.77E-01	3.86E-03	5.68E-04
05:00.80	4.34E-01	5.77E-03	2.14E-03	1.73E-02	5.72E-01	4.32E-03	6.01E-04
05:00.87	4.42E-01	5.80E-03	2.08E-03	1.62E-02	5.81E-01	4.08E-03	5.86E-04
05:00.93	4.43E-01	5.65E-03	2.03E-03	1.55E-02	5.91E-01	3.97E-03	5.88E-04
05:01.00	4.42E-01	5.79E-03	1.96E-03	1.39E-02	6.15E-01	3.79E-03	5.53E-04

2B: Statistics generated by FaceReader analyzing students' facial states.



A dominant facial state is identified based on the statistics. FaceReader calls a new dominant facial state when the new facial state persists longer than 0.5 seconds.

2C: Graph illustrating the different facial state statistics.



Time during which student saw water-reboiling.
Facial states the student exhibited during the time when the result of the water-reboiling demonstration was revealed. In this case, the student showed visible as well as machine detectable facial state changes.

2D: Dominant facial states in chronological order.

Figure 2. Example of student FMES change and FaceReader data.

Students were also categorized into conceptual change (CC) and non-conceptual change (NCC) groups based on their pre- and posttests. Then, data were analyzed through the application of the decision tree methodology. Decision tree is a data-mining technique often used for prediction (See Figure 3). A decision tree is consisted of nodes and leaves with each node a logical divergent point where a particular characteristic of the data would be tested and the data split accordingly. The leaves represent the expected values at the point.

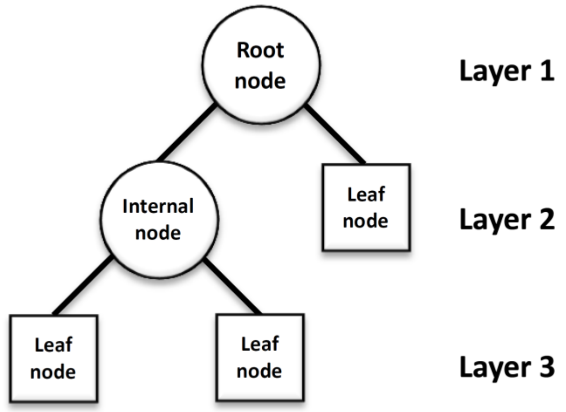


Figure 3. Basic structure of a decision tree.

All decision trees are built through recursion. Decision trees are also not built upon various assumptions, such as normal distribution; collinearity or correlation between explanatory variables can also be ignored.

The current study has adopted the Classification and Regression Trees (CART) (Breiman, Friedman, Stone, & Olshen, 1984) algorithm and built its decision trees using R (v. 3.0.2). Through the decision tree method, the current proposal would attempt to predict if students would undergo conceptual change based on their FMES data.

RESULTS

The current study collected a total of 86 students' facial recognition data, out of which 30 underwent conceptual change and 56 did not undergo conceptual change. Table 1 shows the distribution of students' dominant facial expression frequency in the five experimental segments. Accordingly, other than the Textual Instruction segment, the proportions of students with negative expressions were higher in all the segments. The Textual Instruction segment was evenly split between negative expressions and surprised. In addition, students exhibiting positive expressions only appeared in Video Segment 1 and Video Segment 2. In Video Segment 3, Textual Instruction, and Animated Instruction, on the other hand, only negative expression and surprised were found as dominant expressions.

Figure 4 shows dominant expression frequencies of students with and without conceptual change for the five segments examined. With regard to dominant expression distributions, negative expression was higher than surprised in all segments, except Textual Instruction. Moreover, there is no significant difference ($p>.05$) between the dominant expressions of students with and without conceptual change. On the other hand, the Textual Instruction segment was split between negative expression and surprised; for dominant expression distribution, there is also no significant difference ($p>.05$) between those with and without conceptual change. Lastly, students with positive expressions during Video Segment 1 or Video Segment 2 were found to have no conceptual change.

In summary, it was found that during learning, the proportion of students with negative expression as their dominant expression was higher. This was followed by surprised. Positive expression was the least frequent dominant expression, and it was only found in Video

Segment 1 or Video Segment 2. Students exhibiting positive expressions were also found to be those with no conceptual change.

Table 1. Frequency Distribution of Dominant Expressions for the five experimental video segments.

Segment / Dominant Exp.	Video Segment 1		Video Segment 2		Video Segment 3		Textual Instruction		Animated Instruction	
	Student	%	Student	%	Student	%	Student	%	Student	%
Neg. Expression	49	57	52	60	55	64	44	51	56	65
Pos. Expression	6	7	1	1	0	0	0	0	0	0
Surprised	31	36	33	38	31	36	42	49	30	35

Note：Pos. Expression: Happy, Neg. Expression: Sad, Angry, Scared, Disgusted.

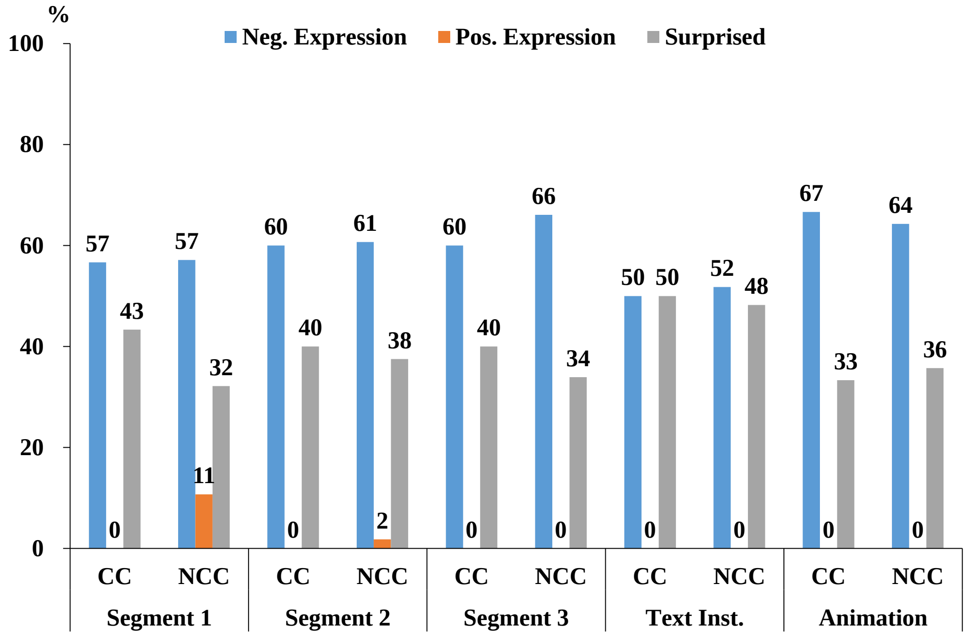


Figure 4. Dominant expressions frequency distribution for conceptually changed and no conceptually changed students during the five experimental segments.

Then, we took one step further and used R (version 3.0.2) to construct the Classification and Regression Trees (CART) (Breiman et al., 1984), with the dominant expressions in the chosen five segments set as the explanatory variable, to make predictions on students' conceptual changes. The decision tree model is shown in Figure 5.

Based on Figure 5, it became apparent that when students' dominant expression was "Surprised" during the first video segment and "Negative" expressions during the third video segment, it could be predicted that students would fall under the conceptually change group (Among the seven students in the group, five underwent conceptual change, two had no conceptual change). Furthermore, when students' dominant expressions were "Surprised" in both first and third video segments, then we could predict these students would end up in the no conceptual change category (Among the 17 students in the group, seven underwent conceptual change, ten had no conceptual change). Lastly, if the dominant expression in the first video segment was "Not Surprised", then it could be predicted that the students would not undergo conceptual change (Among the 44 students in the group, 14 underwent conceptual change, 30 had no conceptual change). The average accurate prediction rate of this decision tree model is 66%.

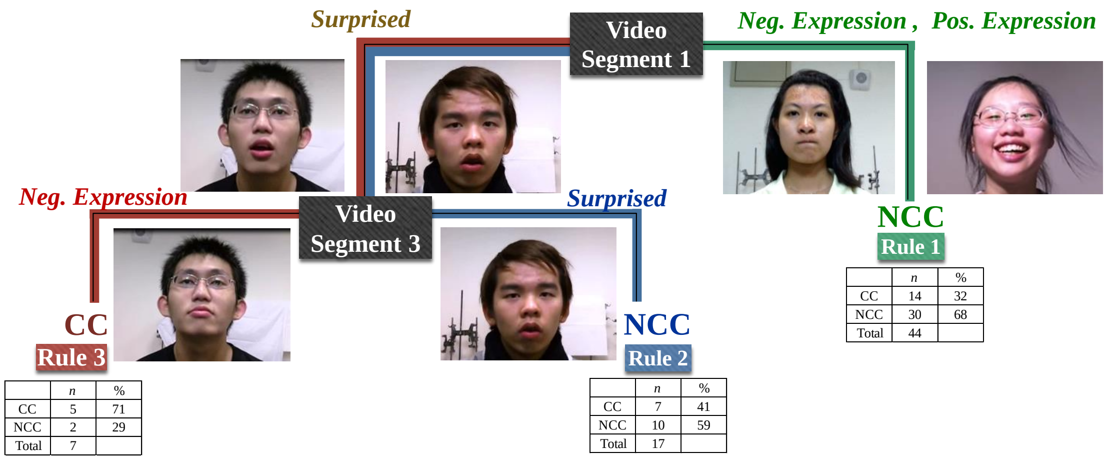


Figure 5. Decision tree model.

For research question 2, we have induced the rules from the 10,000 traditional decision tree models, and then developed a general model, Tree-Forest Model, to predict the status of students' conceptual change (See Table 2). This Tree-Forest Model would modify the decision tree model and accordingly, the decision tree model in Figure 5 can be seen within this model. That is, the decision tree model was based on Rules 1, 2, and 3. Moreover, we can also see that Figure 5 did not include other information. For example, if students' dominant expression in the first video segment is Surprised, and negative expressions for the second or third video segments, then it could be predicted that the student would undergo conceptual change (see Rule 3 & Rule 4 in Table 2). In contrast, if the student's dominant expression in the first and second video segments, or in the first and third video segments, were Surprised, then it could be predicted that the students would not undergo conceptual change (see Rule 2 & Rule 5 in Table 2). In other words, this model could provide the predictive results of a single decision tree as well as the overall trend of the dataset at hand.

Table 2 Tree-Forest Model (Partial)

No.	Rules	Repeated %	Predicted Result
Rule 1	**Video Segment 1** = Neg. Expression, Pos. Expression	96	NCC
Rule 2	**Video Segment 1** = Surprised, **Video Segment 3** = Surprised	82	NCC
Rule 3	**Video Segment 1** = Surprised, **Video Segment 3** = Neg. Expression	82	CC
Rule 4	**Video Segment 1** = Surprised, **Video Segment 2** = Neg. Expression	14	CC
Rule 5	**Video Segment 1** = Surprised, **Video Segment 2** = Surprised	14	NCC

DISCUSSIONS AND CONCLUSIONS

As stated above, conceptual conflict research has gained great attention from science education researchers for the past two decades. This study puts one more step further to show how students' facial microexpression states provided profound information about their responses to counter intuitive scientific phenomenon via a systematic approach that has predictive power of students' performance in science learning. We recognized the importance of facial expression of "surprise" as an indicator to differentiate students as either conceptually changed or no conceptual change in conceptual conflict scenarios. Such scenarios would act as a trigger for students' surprised facial expression. It is our hypothesis that it is because these students possess sufficient prior knowledge about the relations among the three factors (temperature, air pressure, and the boiling point), that they were capable of recognizing the inconsistencies between their knowledge and the observed phenomenon. However, when the phenomenon was shown to the students repeatedly, then the emergence of negative facial expressions would be the indicator for conceptual change instead. As such, although exhibiting the surprise facial expression would not necessarily always signify conceptual change, it can still provide relevant information to teachers so that they would be able to distinguish whether or not students were engaged in the activities and subsequently could achieve conceptual change. The findings of the current study are in line with other studies where facial expression or affective states were found to be related to learning (Chen et al., 2013; Craig, D'Mello, Witherspoon, & Graesser, 2008; Shen, Wang, & Shen, 2009). While humans' complex facial expressions might correspond to their cognition, still very little is known about such correspondences. Consequently, much work remains ahead for educators to map out the intricate relations between facial expressions and cognition.

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REFERENCES

Breiman, L., Friedman, J. H., Stone, C. J., & Olshen, R. A. (1984). *Classification and regression trees*. Pacific Grove, CA: Wadsworth.

Chen, M. Y., Lughofer, E. D., Cheng Lin, K., Huang, T. C., Hung, J. C., Yen, N. Y., & Ju Chen, S. (2013). Facial emotion recognition towards affective computing-based learning. *Library Hi Tech, 31*(2), 294-307. doi:doi:10.1108/07378831311329068

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*(1), 1-49.

Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching, 35*(6), 623-654.

Chiu, M.-H., Chou, C.-C., Wu, W.-L., & Liaw, H. (2014). The role of facial microexpression state (FMES) change in the process of conceptual conflict. *British Journal of Educational Technology, 45*(3), 471-486. doi:10.1111/bjet.12126

Craig, S. D., D'Mello, S., Witherspoon, A., & Graesser, A. (2008). Emote aloud during learning with AutoTutor: Applying the Facial Action Coding System to cognitive-affective states during learning. *Cognition and Emotion, 22*(5), 777-788.

Ekman, P. (1970). Universal facial expressions of emotion. *California Mental Health Research Digest*, *8*, 151-158.

Ekman, P. (1993). Facial expression and emotion. *American Psychologist, 48*(4), 384-392.

Ekman, P. (1999). Facial expressions. In T. Dalgleish & M. Power (Eds.), *Handbook of Cognition and Emotion*. New York, NY: John Wiley & Sons, Ltd.

Liaw, H. L., Chiu, M.-H., & Chou, C.-C. (2014). Using facial recognition technology in the exploration of student responses to conceptual conflict phenomenon. *Chemistry Education Research and Practice, 15*, 824-834. doi:10.1039/c4rp00103f

Matsumoto, D., & Hwang, H. (2011). Evidence for training the ability to read microexpressions of emotion. *Motivation and Emotion, 35*(2), 181-191. doi:10.1007/s11031-011-9212-2

Merenluoto, K., & Lehtinen, E. (2004). Number concept and conceptual change: Towards a systematic model of the processes of change. *Learning and Instruction, 14*, 519-534.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic Emotions in Students' Self-Regulated Learning and Achievement: A Program of Qualitative and Quantitative Research. *Educational Psychologist, 37*(2), 91-105. doi:10.1207/s15326985ep3702_4

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Scott, P. H., Asoko, H. M., & Driver, R. H. (1992). Teaching for conceptual change: A review of strategies. In R. Duit, F. Goldberg, H. Niederer (Eds.), *Research in Physics Learning: Theoretical Issues and Empirical Studies* (pp. 310-329). Kiel: IPN.

Shen, L., Wang, M., & Shen, R. (2009). Affective e-learning: Using "Emotional" data to improve learning in pervasive learning environment. *Educational Technology & Society, 12*(2), 176-189.

White, R., & Gunstone, R. (1992). Prediction-observation-explanation. In R. White & R. Gunstone (Eds.), *Probing Understanding* (pp. 44-64). London: Falmer Press.

MULTIMODAL SCIENCE LEARNING: A HYBRID MODEL OF CONCEPTUAL CHANGE.

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Abstract: Multimodal research proposes that knowledge and meaning are transmitted through a range of responses types including verbal and written language, drawings and gesture (Kress et al, 2001). This paper explores the application of this multimodal approach to conceptual change in science. The study focused on a qualitative analysis of the knowledge and ideas demonstrated by a small group of 11 year old children during practical science activities which focused on revealing and challenging ideas about floating and sinking. Results demonstrated that the children's ideas could be developed using specifically designed conceptual challenge tasks and that they frequently employed a range of communication domains including gesture in order to discuss their ideas. The gestures that the children produced were fundamental to understanding the science concepts and ideas that the children already held. Interestingly the gestures also were able to reveal the way that the children's ideas changed and developed throughout the course of the activities. The resulting changes in ideas were mapped using a timeline approach originally developed by Givry and Tiberghein (2012). The mapped timeline was subsequently related to popular models of conceptual change (Vosniadou & Brewer, 1987; diSessa, 1988, Karmiloff-Smith, 1992; Luffiego et al, 1994) in order to explore their utility for explaining the data. Whilst all of the models appeared to explain some aspects of the changes, no model could successfully capture all elements; this led to the proposal of a hybrid model of conceptual change. The hybrid model builds on the work of Taber (2008) in order to demonstrate how changes can progress through different levels of representation prior as well as differences in cognitive structures.

Keywords: Multimodality, conceptual change, gestures

INTRODUCTION

Research interest in children's ideas in science has a long established history in science education research (as shown in Vosniadou, 2008). This research has historically adopted a constructivist approach in order to understand both the existing ideas that children have about science concepts and the way that these are changed following formal tuition (Driver et al, 1994). This vast body of research has resulted in the development of a number of models of conceptual change. A review of the different models revealed at least 12 that were popular in contemporary literature with the following four Vosniadou & Brewer (1987), diSessa (1988), Karmiloff-Smith (1992); Luffiego et al. (1994) being cited regularly in order to explain the cognitive processes that underpin learning. As shown in table 1 each of these models differs in its depth and scope and the science subject that is explored, for example Vosniadou and Brewer's work (1987) explores astronomy concepts whilst diSessa's work (1988) focuses on the development of ideas in physics. Notably the existing research also explores the changes in ideas using different participants groups.

Table 1: Summary of the four models of conceptual change that were explored in this study.

Model of Conceptual Change	**What is conceptual change?**	**What changes?**	**How does it occur?**	**Evidence for Model**	**What is prior knowledge?**
Vosniadou's Weak / Radical Restructuring Approach (1987 onwards)	A change in theory.	A change in the mental models that are applied when answering questions (proposed to reflect changes in the underlying theory).	Two processes of restructuring: Weak – addition of new relations within conceptual structures, organisation of knowledge into abstract relational schemata; Radical – a shift in the theory held.	Studies exploring children's acquisition of astronomy concepts, one study in physics and recent application to mathematics education.	Obstacle because it can give rise to synthetic models or misconceptions as well as vehicle for change.
diSessa's Knowledge in Pieces Approach (1988 onwards)	The process that organises what is known into coherent theory structures.	A change in the structuring and coordination of the information held.	Changes in the relations between p-prims, the development of overarching structures which coordinate the p-prims (co-ordination classes and causal nets). There is a move from fragmentation to coherency.	College and undergraduate physics students. Recent application by Taber (2008) to chemistry.	Foundation of disorganised knowledge.
Karmiloff-Smith' Representational Re-description Model (1992)	The re-description of knowledge from implicit (tacit) and context bound to explicit and	A change in the availability of knowledge across contexts.	Initial knowledge is tacit and unavailable for verbal report both within the individual	Studies with very young children investigating object permanence and basic	Tacit procedural knowledge that forms the foundation of later learning.

	context free, a change in coding format.		and to others. The context bound procedural knowledge is represented through a four stage approach so that it is transformed to explicit knowledge that at the fourth level becomes available for verbal report.	level physics concepts. Recent application by Phillips (2007) to the balance scale problem.	
Luffiego's Systemic Model of Conceptual Change (1994)	The self-facilitated process of evolution in cognitive structures.	A change in the structure and relationships of concepts contained in schema.	Two processes of restructuring: Weak – the addition of new information, changes in the relationships between concepts and modification of schema; Radical – change in attractor concepts, formation of attractor subschema.	Sharp & Kuerbis' (2006) study of children's development of astronomy concepts. Bloom's (2001) study of the development of the concept of density.	Foundation of conceptual change by acting as an attractor for incoming information.

This limitation has often restricted the possibility for comparisons to be undertaken, which has previously been acknowledged as one of the weaknesses of this research field (diSessa, 2006). This work aimed to specifically address this issue by exploring the application of the four models of conceptual change in order to explain the results draw from one group of participants.

Recently explorations of multimodality and the way that children can use a range of responses including gestures to communicate their science ideas has led to the conclusion that research and indeed teachers need to attend more to other levels of communication as they contain important aspects of knowledge that may not be present in verbal response types (Kress et al, 2001; Goldin-Meadows, 2000; Crowder & Newman, 1993; Goldin-Meadows et al, 1993). This work has highlighted that children sometimes communicate ideas in gesture that are not available in any other response type (e.g. verbally). For example, Crowder and Newman's study (1993) demonstrated that children gestures were used in three ways, on some occasions gestures were redundant and contained no information or explanations relevant to the topic or the verbal response that children provided. In some cases children's gestures contained conceptual information that supported the content of verbal responses. Finally, sometimes children used gestures that contained conceptual ideas that did not appear in speech and therefore offered a richer description of the ideas that children held. Similar findings were presented by Kress et al. (2001). In Kress' work gestures were proposed to be an important aspect of communication, whilst Goldin-Meadows et al. (1993) proposed that gestures could be used to identify when knowledge was in transition. Taken as a whole the studies support the importance of exploring the underlying meaning contained in children's gestures. The project detailed here aimed to address this new and evolving field by exploring children's ideas about floating and sinking using a multimodal approach, specifically the work explored children verbal, written, drawing and gesture based responses elicited during practical science activities.

Floating and sinking was investigated as this area of science represented some concepts that could be directly observed and the activities were concrete in nature in order to provide a potential platform where children may use gestures in support of their explanations. Furthermore this area of science had been subject to previous studies and allowed for comparisons to be made to previous frameworks of understanding identified in the literature (Inhelder & Piaget, 1958; Howe et al. 1990; Havu-Nuutien, 2005).

METHOD

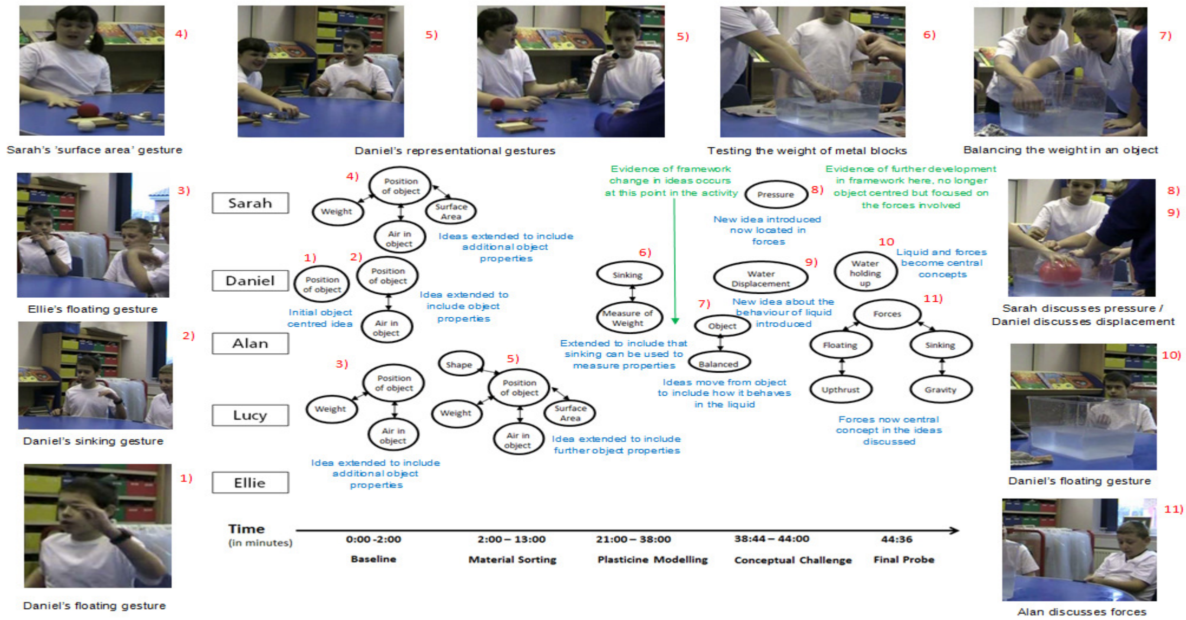
This study focused on a 45 minutes block of activities undertaken with five 11 year old primary school children. The children were all being educated in a mainstream English primary school and worked together in a group to undertake a number of practical science activities exploring ideas about floating and sinking. The activities included discussions around what the children thought floating and sinking was, material sorting and experimentation in order to test ideas about what kind of materials would float. This was followed by a demonstration of upthrust force using an inflated balloon which was pushed down into the water and a discussion of the Archimedes story. The children's ideas were continually probed during the activities using open-ended questions and a dialogic teaching approach.

The activities were video recorded, transcribed in full in order to capture all levels of communication including gestures. The transcript was analysed thematically in order to reveal the different concepts that the children used throughout the course of the activities, the results were then mapped to a timeline using guidance from Givry and Tiberghein (2012). Givry and Tiberghein developed a timeline approach to mapping children's ideas within a single teaching sequence, this approach aimed to capture the links made between concepts in order to propose the underlying networks of ideas that children were developing. In this current study the timeline approach was further developed in order to link examples of gestures with the children's verbal responses thus providing a more holistic understanding of the concepts that were being communicated. Furthermore, this approach permitted the links between different concepts to be drawn out and comparisons to the models of conceptual change to be made. Points of change in ideas were annotated on the timeline and used in order to inform the subsequent analysis and discussion of findings. Specifically the analysis tracked the children's use of key conceptual ideas which were expressed both verbally through gesture transmission. When the children used linking words such as 'and' the terms were connected in order to build the networks shown in figure 1. When the children changed their explanation or moved on this was annotated in the timeline.

The study adopted appropriate ethical procedures in line with the university's policies. All children's names were changed to pseudonyms.

RESULTS

Figure 1: the timeline analysis developed from the activities that the children completed while exploring their ideas about floating and sinking.



The results revealed that the children initially used a single concept in order to explain what they thought floating and sinking was (1 in Figure 1). This concept was associated with a related representational gesture that provided additional information not contained in their speech. Notably, Daniel's gesture highlighted how he thought the object explored behaved in the water. This was interpreted as the object remaining stationary at the top of the water. It is proposed that the gesture and speech combined support the notion that the initial concepts of floating and sinking was related to the position of the object in the water. This single concept idea was extended to included additional information (2) and again was accompanied by a representational gesture which this time shows how Daniel thought a sinking object would behave. In this gesture Daniel represented a movement through the air in a downwards motion. In terms of change, this point in the activities could illustrate evidence of a weak form of conceptual change as the core concept (e.g. the location of the object in the water) remains central to the discussion, however, in addition the children also discussed the importance of the presence of air in the object.

The evolution of the children's ideas continued to adopt what could be perceived as a weak form of conceptual change supported by gestures that extended the meaning contained in speech (3, 4, and 5) but also revealing increasing levels of complexity. Notably as the discussions developed the children added properties to the object that they thought would help to decide whether or not it would float or sink, thus demonstrating that they perceived a number of object properties to be associated with these concepts. As the activities moved on the children began to associate the floating and sinking activity with a method for testing the weight of the object (6). This point marked a departure from the concepts previously used and may provide evidence of knowledge fragmentation, e.g. that different ideas were being drawn into their discussion of the concepts. The children then returned to a discussion of object properties but this time with new ideas not previously represented (7). Specifically the children discussed the need for there to be balance in order for the object to float. The children had not previously used this idea and therefore it is proposed that this marks a point of departure from ideas discussed earlier.

New concepts were introduced again (8, 9). Specifically the children introduced the notions of pressure (during which they began to sing "Under Pressure" a popular song in the UK) and the notion of water displacement. Whilst water displacement was discussed during the conceptual change activities the discussion of pressure was drawn from the children's own ideas in order to explain what they thought the upthrust force was. It is proposed that this presented a new concept that the children had not previously associated with the concepts of floating and sinking.

The timeline then appears to mark a point of more radical restructuring (10, 11). Here, the children ceased discussing just the object properties and began to discuss how '*water holds the object up*'. This discussion revealed a new concept introduced during the conceptual challenge task but not discussed by the children before. Interestingly, there is also evidence of a change in the representational gesture that Daniel used when discussing floating. By comparing gestures (1-10), it is possible to see that he had changed the orientation of his hand from palm facing downward to palm facing upwards. This subtle but important change in gesture may be a non-verbal cue to the changes that have occurred in his ideas. Finally, the children now only discussed floating and sinking by applying a forces framework (11). The forces framework is distinctly different to the children's earlier discussions and it contained ideas that had not been previously applied to the floating and sinking activities. It is proposed that this finding demonstrates a more scientific explanation of what floating and sinking are and thus may support the notion that the children's ideas were more radically restructured with a new central concept now guiding their ideas.

DISCUSSION AND CONCLUSIONS

The result drawn from this study appeared to suggest a hybrid model of conceptual change, which seems appropriate particularly if the initial mapping of ideas takes the basis of diSessa's p-prims (1988). These new concepts are mapped in isolation to specific stimuli. Such stimuli may not always be available for verbal report and may therefore only be identifiable when analysing gesture alongside the verbal reports given. Thus Karmiloff-Smith's (1992) views are essential. Once further experience is gained, these p-prims begin to evolve using both weak and radical processes (Vosniadou & Brewer, 1987). Sometimes, for example, new information is merely added giving rise to weak changes. At other times, however, the new information forms the core of the concept and the existing p-prim becomes attached as a major component giving rise to more radical changes. As it is not always possible to predict the pattern of development in children's ideas Luffiego et al's model of conceptual change involving chaotic systems (1994) may explain this finding.

Whilst the data discussed in this paper contains an analysis based on work with just five children it may be vulnerable to the criticism that this work would not be generalisable to other children or other concept areas. However, this work was embedded within a much larger project and the results are broadly similar across other groups of children within this age range, furthermore the broader study also explored children's ideas about electricity. The timeline analysis approach to mapping the evolution of children's ideas during practical activities about electricity demonstrated some further support for the approach's application. Taken as a whole the results support the notion that it is important to explore approaches to mapping ideas in this way in order to capture change and to capture elements of change that may be otherwise missed. However, this level of analysis was extremely time consuming and requires further replication in order to more strongly support its application.

In conclusion, this work reveals that it is important to explore all aspects of children's communication (including gesture) if we are to understand the ideas that they already have and the way that these change following tuition, furthermore it would appear that one single model of conceptual change does not account for the different layers of change that can be observed when ideas are explored more holistically and subsequent work should aim to explore the utility of the notion of hybridity as an explanation for conceptual change.

REFERENCES

Bloom, J. W. (2001). Discourse, cognition and chaotic systems: An examination of students' arguments about density. *The Journal of Learning Science,* 10:4, 447-492.

Crowder, E. M., & Newman, D. (1993). Telling what they know: the role of gesture and language in children's scientific explanations. *Pragmatics and Cognition,* **1**, 341-376.

diSessa, A. A. (1988). Knowledge in Pieces. In G. Forman, & P. B. Pufall (Eds.) *Constructivism in the Computer Age* (pp. 49-70) Hillsdale, NJ: Lawrence Erlbaum Associates Publishing.

diSessa, A. (2006). A history of conceptual change research: threads and fault lines, In: K. Sawyer. *The Cambridge Handbook of the Learning Sciences.* Cambridge MA: Cambridge University Press. 265-282.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing Scientific knowledge in the classroom. *Educational Researcher,* **23:7**, 5-12.

Givry, D., & Tiberghein, A. (2012). Studying Students' Learning Processes Used During Physics Teaching Sequence about Gas with Networks of Ideas and Their Domain of Applicability. *International Journal of Science Education,* **34:2**, 223-249.

Goldin-Meadows, S., Alibali, M. W., & Church, R. B. (1993). Transitions in Concept Acquisition: Using the Hand to Read the Mind. *Psychological Review,* **100:2**, 279-297.

Goldin-Meadow, S. (2000). Beyond Words: The Importance of Gesture to Researchers and Learners. *Child Development,* **71:1**, 231-239.

Havu-Nuutinen, S. (2005). Examining young children's conceptual change process in floating and sinking from a social constructivist perspective. *International Journal of Science Education,* **27:3**, 259-279.

Howe, C., Tolmie, A., & Radgers, C. (1990). Physics in the Primary School: Peer Interaction and the Understanding of Floating and Sinking. *European Journal of Psychology of Education,* **V:4**, 459-475.

Inhelder, B., & Piaget, J. (1958). The Law of Floating Bodies and the Elimination of Contradictions. In B. Inhelder, & J. Piaget *The Growth of Logical Thinking From Childhood to Adolescence* (pp. 20 – 45). London: Routledge & Kegan Paul Ltd.

Karmiloff-Smith, A. (1992). *Beyond Modularity: A Developmental Perspective on Cognitive Science.* Cambridge, MA: The MIT Press.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal Teaching and Learning: rhetorics of the science classroom.* London: Continuum.

Luffiego, M., Bastida, M. F., Ramos, F., & Soto, J. (1994). Systemic model of conceptual evolution. *International Journal of Science Education*, **16:3**, 305-313.

Philips, S. (2007) *Children's performance on and understanding of the balance scale problem: the effects of adult support.* PhD thesis, University Of Strathclyde. [online] available from: http://strathprints.strath.ac.uk/5977/ [accessed 30th July 2013]

Sharp, J. G. & Kuerbis, P. (2006). Children's ideas about the solar system and the chaos in learning science. *Science Education,* **90:1**, 124-147.

Taber, K. S. (2008). Conceptual Resources for Learning Science: Issues of transience and grain-size in cognition and cognitive structure. *International Journal of Science Education,* **8:25**, 1027-1053.

Vosniadou, S., & Brewer, W. F. (1987). Theories of Knowledge Restructuring in Development. *Review of Educational Psychology,* **57:1**, 51-67.

Vosniadou, S. (2008). *International Handbook of Research on Conceptual Change.* Oxon: Routledge.

CONCEPTUAL PROGRESSION – ARE THERE ANY *PATHS*? USING CONCEPTS MAPS TO MONITOR STUDENT PROGRESSION AND CAUSAL PATHS IN LONG-TERM INQUIRY

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Abstract : Sustainable development requires critical thinking and scientific knowledge. Inquiry learning, promoted across Europe, could promote skills to help future citizens understand and take responsible informed decisions about long-term effects. Inquiry can be conceptualized as a process where student's naïve explanatory models of biological phenomena are progressively refined, and where student's understanding - initially vague ideas - are refined as students experiment or read about experiments into additional and more precise concepts and causal links guided by questions. Understanding the paths that this progression follows is crucial in designing learning environments, in assisting and guiding students and in assessment. It is often assumed that concepts are acquired linearly from "simple" to "complex". Learning progression has also been proposed to be "roaming a landscape" rather than "climbing a ladder" (Zabel & Gropengiesser, 2011). However, determining diverse and unpredictable student conceptual paths is quite difficult and pre- / post-tests do not document the multiple steps students might follow. Furthermore, assessing students' mental models is not directly possible, and generally relies on analysis of student productions. Here we propose a method for monitoring student progression that is based on extracting concepts and causal links expressed in successive students' written productions and mapping them onto concept maps of institutionalized models (the models instruction is geared towards) for each version. In order to test the instrument, we will analyze one year of students' productions in a shared writing space during inquiry. We argue that this method could inform inquiry guidance, help designing learning environments, and identify conceptual difficulties in student progression. Time sequence in which concepts / links appear (early or late) allows discussion of causes for late-appearing model items as i) difficulties in learning, ii) weaknesses of designs or iii) epistemic specificities of the knowledge structure in resources used by students.

Keywords: conceptual paths, inquiry, student progression measure, concept mapping, visualizing conceptual change.

INTRODUCTION

A major aim of science teaching is developing skills to help future citizens understand and take responsible informed decisions about long-term effects to manage sustainable development, the focus of the ESERA 2015 conference. Inquiry learning has been promoted to develop both critical thinking and scientific knowledge. This contribution addresses one issue in guided inquiry learning: how to follow and assess student's progress *during* the process of learning. Designing learning environments for inquiry with guidance during instruction requires insight into students' conceptual progression. Monitoring student progression is quite difficult and pre- / post-tests cannot document the multiple conceptual steps students follow during their learning processes.

The goal of this research is to explore conceptual progression of students during the learning process, to analyze the paths - if any - it might follow, and discuss the sequence of conceptual progression in order to gain insight into learning difficulties, design limitations, or epistemological constraints.

It is often assumed that concepts are acquired linearly, from “simple” to “complex”. Some research suggests that learning progression might well be “roaming a landscape” rather than “climbing a ladder” (Zabel & Gropengiesser, 2011). Determining such diverse and unpredictable conceptual paths is quite difficult, especially in long-term interventions. Documenting the multiple conceptual steps students might follow during their learning processes requires multiple points of data along the duration of learning progression that are not commonly available.

The central questions in current biology research are explanations of underlying mechanisms (Morange, 2003). Scientific explanations are by essence *models* of phenomena (Tiberghien, 1994). Natural phenomena can only be accessed in science by experiments, which are designed within models. Models, according to Martinand (1996) are i) hypothetical, ii) modifiable (with new data, progress of knowledge, new interpretations…), iii) relevant to a particular class of problems and iv) of limited validity (i.e. cannot be 100% “true”). Science teaching should guide students towards model-using skills for explaining or predicting phenomena, monitoring should focus on learning outcomes such as using a given model for prediction or explanation (Biggs, 2003).

Assessing student’s mental models of natural phenomena is not directly possible. We would like to stress that we do not present an assumption about what *form* these models might take within students’ minds, when we refer to understanding we refer to *expressions* of students’ understanding. More precisely, as we shall explain below, we analyze written data produced by students.

Models to be learned and taught are defined by the school or other authorities and such choices will not be discussed here. We will refer to these particular models that instruction is aiming at as *institutionalized models* (Brousseau, 1998). This implies that there certainly are *other* models – some much more elaborate - than the one chosen in this particular curricular context. Indeed, a crucial idea here is that the particular model students should be capable of using is neither true nor false, it is appropriate for the problems addressed and can explain the data the students will be confronted to. So this *institutionalized model* is neither a model of student’s knowledge structure, nor a model of expert knowledge. This *institutionalized model* could be considered an ideal-type (Weber, 2009), an abstraction of some characteristics of the phenomenon, used for analysis purposes (ideal does not refer here to *perfection*).

We propose using diagrammatic representations of institutional models as a method for visualizing traces of student progression. This methodological choice might suggest a rather cognitivistic view of student knowledge, but that does not reflect our view of understanding. We will discuss a method for monitoring student progression that is based on extracting concepts and causal links expressed in student’s successive written productions and mapping them onto concept maps for each version. Models can be expressed as concept maps (Novak & Cañas, 2008), a powerful way of visualizing concepts (nodes) and their relations (causal links). Indeed, for this research, the institutionalized model was expressed as an ideal-typical concept map onto which model items (concepts and causal links) present in versions of students’ productions can be visualized.

This method provides insight into progression of students’ understanding. It can visualize stages of progression in ways that allows comparison across years and different designs.

Our main research question is: I) How can we identify and model conceptual *paths (if any)* that students follow while investigating biology in an Inquiry Based Learning (IBL) design? This led to other sub-questions: IIa) Can this method reveal over years repeated time patterns for concepts, causal chains? On a semantic level: IIb) Can this method help identify conceptual difficulties in the learning landscape (such as conceptual obstacles or cognitive construals), weaknesses of designs or epistemic specificities of the knowledge structure in resources used by students?

METHODS

This research is part of a long-term design-based (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004) research study on inquiry learning being conducted since 2006 in advanced high school classes in Geneva, totaling nearly one hundred students so far. Each intervention lasted most of one school year, in a standard class, with standard time and assessment requirements; we believe it can be considered a real-world teaching situation. The curriculum covered molecular biology, genetics, and immunology. The learning design was inspired by a knowledge-building community of learners, was structured for cooperative learning and was scaffolded by a shared wiki in which students wrote their current understanding. They investigated answers to inquiry questions by experimenting and reading authentic resources. Early in the investigation process and close to the end, students presented their understanding to peers, leading to confrontation of knowledge, question redefinition. The student's efforts resulted in a brochure critical for student's preparation of important exams, making it a crucial document to them. An inquiry cycle lasted 3 to 4 weeks, after which the class addressed a new chapter.

Data was collected from the wiki's history recordings. Conceptual progression was traced by comparing all revisions of student text, i.e. multiple records of students' productions in a shared writing space (wiki) supporting inquiry. Since the teacher is also one of the authors, using only data from written student productions minimizes possible biases.

We plan to compare seven cohorts of students in the same learning design and to search for common patterns and epistemological components such as concept links and linear or multiple causalities. For this first exploratory methodological study, we selected one year (2006) and one student inquiry question: "How do the correct antibodies appear in response to a given pathogen called X" as it was explored by one group of 3-4 students that year during the investigation process (2-3 weeks).

The coding procedure identifies presence and absence of nodes with respect to an ideal-type: We structured the model items (concepts and links) of the institutionalized model in the form of a concept map (Novak & Cañas, 2008) shown in Figure 1. This model was developed by three experienced biology teachers, compared to curriculum requirements and confronted to a large sample of student productions to confirm all concepts and links could be situated on that map.

Institutionalized model

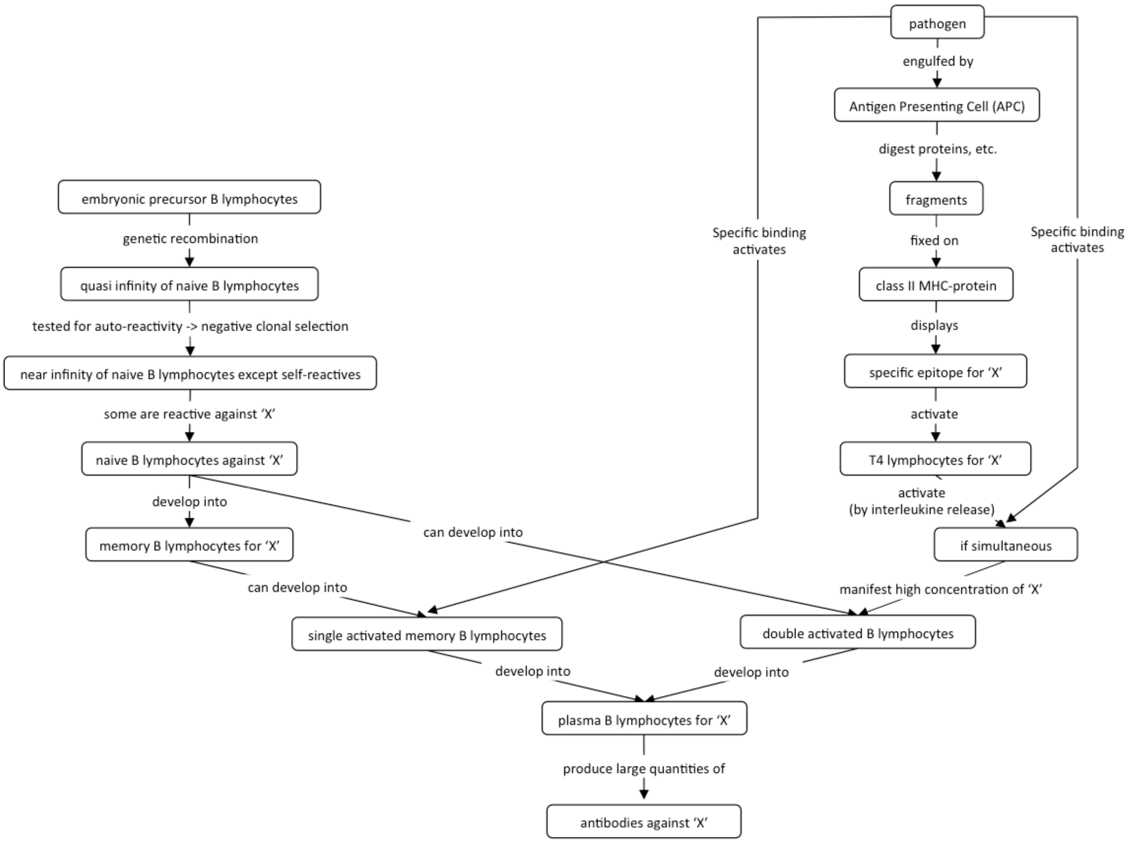

Figure 1. Methodological construct for visualizing traces of student productions in a wiki: the institutionalized model on which were mapped the progression of each group analyzed (see methods).

We searched all 95 versions of students' text for traces of model items (concepts and links). We coded presence or not of each model item by analyzing semantic units of student text for each version. Students' text production grew during 3 weeks of investigation to reach 3820 words. Different possible wordings were accepted as long as semantic equivalence was found. Many revisions did not contain changes in terms of model items but other revisions such as language correction or text reorganizing. In the group analyzed, we found eight *significant* versions, giving insight into as many understanding steps of this particular group.

Coding sheets were produced for each significant version; a sample is shown in Figure 2. When model items were largely present, but some discrepancy was noted, the discrepancy was indicated in a footnote. Model items that were insufficiently explicit were not considered present. Double coding was used to stabilize criteria until more than 90% agreement was reached, then simple coding was applied by the one of the researchers to all versions.

Sample coding sheet

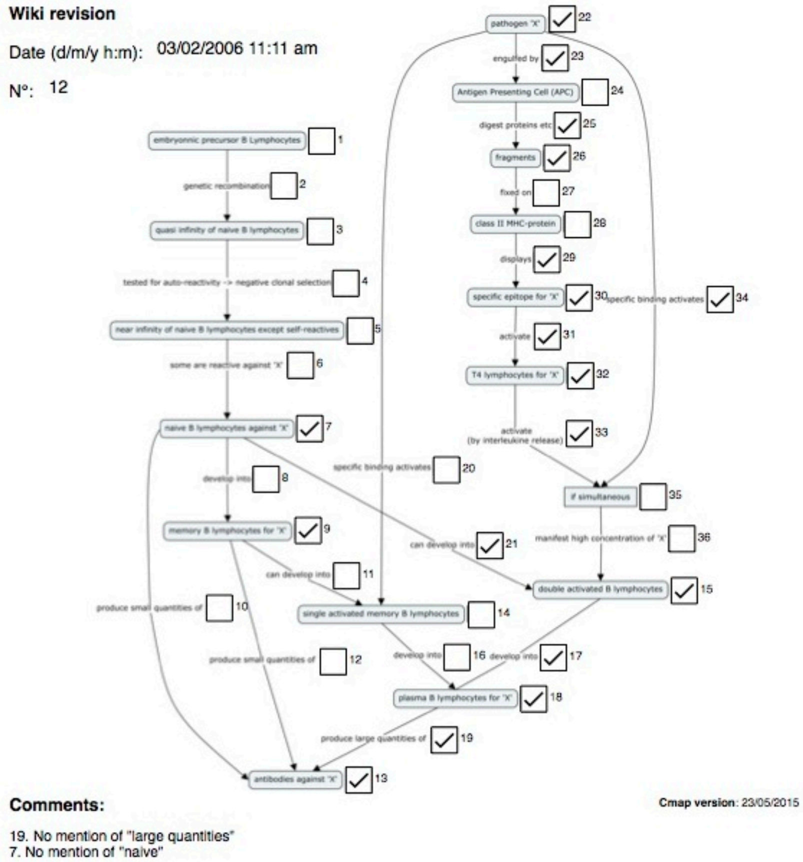

Figure 2. Sample coding sheet for one version (version 12, year 2006). Model items found in that version of student text were checked. Footnotes indicate concepts or links that were partially present and state discrepancies.

A first analysis concerns presence of items: A count of model items is plotted against version numbers (see Figure 3). It was not found to be very informative with respect to monitoring students' progression in model acquisition so other visualizing methods were sought.

A second type of analysis visualizes partial model patterns that appeared in student productions over time: A map visualizes model items found in each significant version by highlighting them on a grayed-out map (cf. Figure 4). Concepts were visualized as dots and links as lines.

A third type of analysis consolidates counts of model items across multiple versions to reveal time patterns. For each model item found we counted occurrences across all significant versions, producing a *prevalence count* for that concept or link. Since a model item never disappeared from student text, we considered this a good indicator of how *early* this item appeared in the progression. To produce the prevalence index, we then standardized these numbers to the total of versions for that year (item *prevalence count* / number of significant versions), and expressed on a percentage scale rounded to the closest integer attached to the item as a dark badge. The size of badges was chosen so that early appearing items got a large badge as in Figure 5.

Together, these three visualization methods allow to investigate and analyze student progression from various angles. Firstly, this method analyzes the time sequence in which concepts / links appear (early or late). This opens possible discussion of causes for late-appearing model items as difficulties in learning, weaknesses of designs or epistemic specificities of the knowledge structure in resources used by students.

Second, this method can search for evidence of conceptual obstacles (Bachelard, 1947) that would render some concepts or links difficult to understand, we would expect them to appear later. Also Coley and Tanner (2015) propose that cognitive construals could explain many misunderstandings in learning biology. We would therefore expect concepts that go against finalism and animism such as clonal selection in our example of immunology to appear *later*.

Third, this method can help searching for structuring concepts (Wiggins & McTighe, 2000) and threshold concepts that are often the points at which students experience difficulty (Meyer, Land, & Baillie, 2010): since their understanding is transformative (occasioning a significant shift in the perception of a subject), and helps understanding several other concepts, we would expect them to systematically appear later and precede the appearance of many other links and concepts. However, fascinating this perspective might be, pinpointing that specific moment of student conceptual progression would require very numerous productions by students that might be difficult to obtain in real-world situations.

RESULTS

A first visualization of concept and links count is shown in Figure 3. It gives some insight into student progression that confirms regular learner's progression. It does not inform about possible paths that are the focus of this article, but implicitly reinforces the conception of student's progression as a ladder-like path. We have elsewhere discussed more relevant measure of global learning achievement (epistemic complexity) that confirmed that adequate learning occurs in the design (Lombard & Schneider, 2013), however the independence of content which was the strength of that approach did not allow investigating conceptual progression trajectories we explore here.

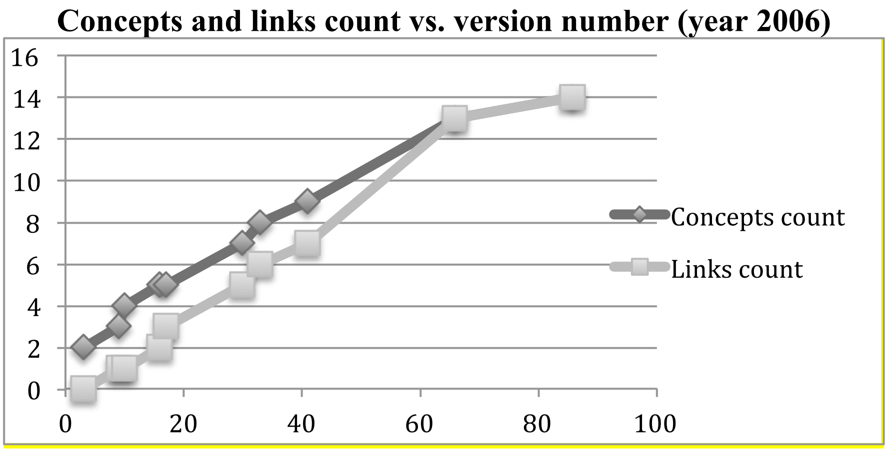

Figure 3. Concepts and links count vs. version number (year 2006). This visualization shows the need for more informative visualization.

A second type of analysis looks at successive versions of student's text during inquiry. By mapping nodes and links onto the institutionalized model, we gain insight into steps and paths of learners understanding. Figure 4 shows all the significant intermediary steps of the progression for one group.

The most striking - and surprising - result is that we did *not* find connected *paths* in student productions. We definitely did not find a ladder, nor a roaming trail: model items appeared in a sort of mosaic manner, gaps in causal chains closing here and there in no understandable pattern. "Path" does not even seem an appropriate term: we might speak of *kangaroo jumps* completing causal chains in small mosaic steps. Causality patterns appear first as numerous short sequences and progressively are connected. Simple linear and short causal chains are linked to include multiple causalities forming a complex model as shown in latest images of Figure 4.

Only late in the investigation were causal chains fully linked. In fact, some remained incomplete even at the end of inquiry in the year analyzed here (2006). In other words, students did not show evidence of having fully achieved the learning goals. We are studying other years and preliminary results show it was fully attained only for one year (2015).

Concepts and links present in successive versions of student productions (2006)

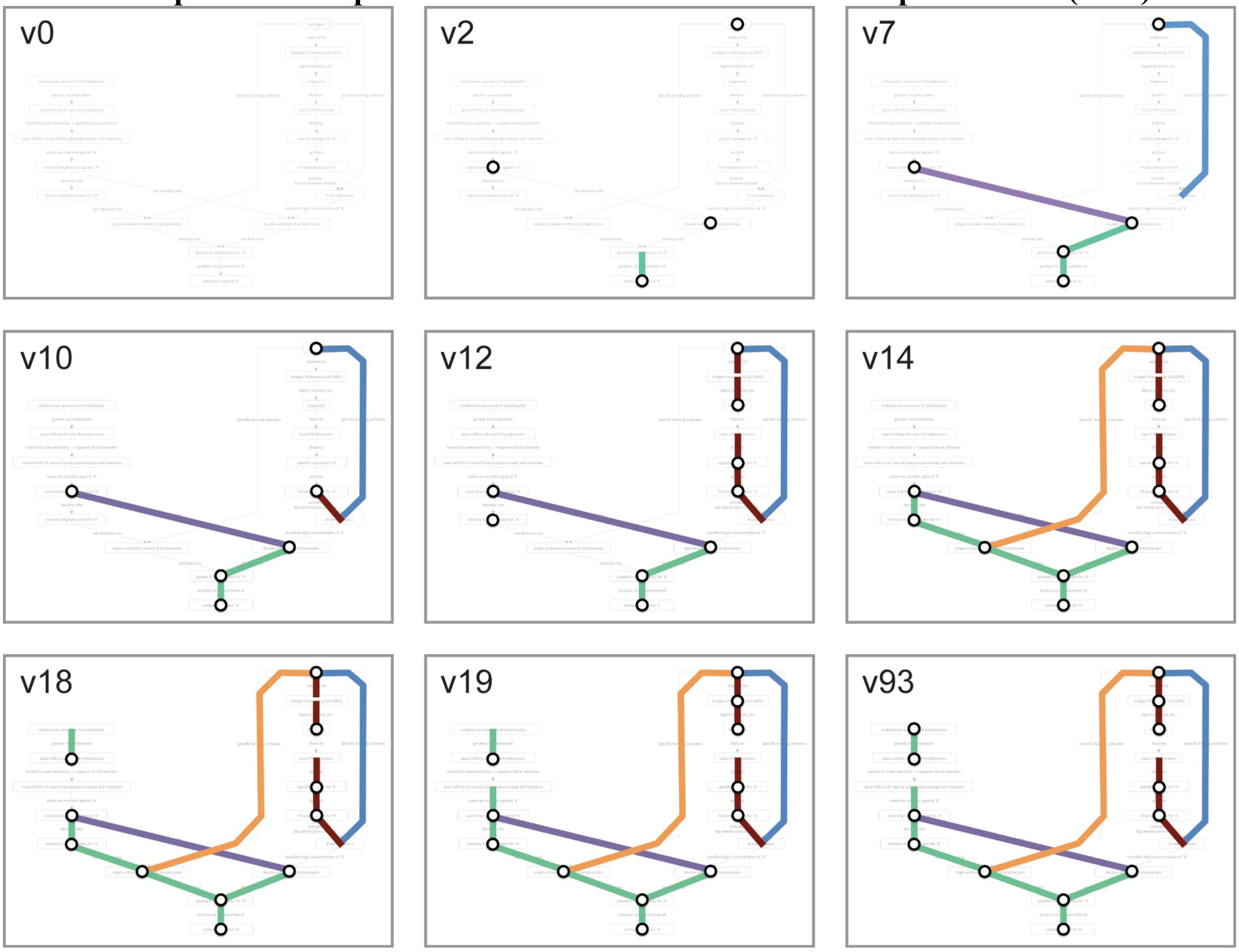

Figure 4. All significant versions along the learning process of one student group. Concepts figured as dots, links as lines (mapped against the grayed-out concept map of the institutionalized model, see methods).

A third type of analysis shows which concepts links appeared early or late as can be seen in Figure 5. Indeed some local causal chains (e.g. B cell activation to produce antibodies) were expressed very early in the investigation process and others were completed later, towards the end of the training sequence (e.g. negative clonal selection of auto-reactive clones, MHC class-II presentation of antigen fragments).

Preliminary analysis (after ESERA conference) of 6 other years suggests that this happened repeatedly: some late-appearing and some early-appearing model items can be identified in each group. This opens the possibility of basing the discussion of student difficulties with complex biology models on explicit data. In other words, we suggest that these visualizations allow analyzing what concepts might be difficult for students, or how we could improve a pedagogical design.

Prevalence index (2006)

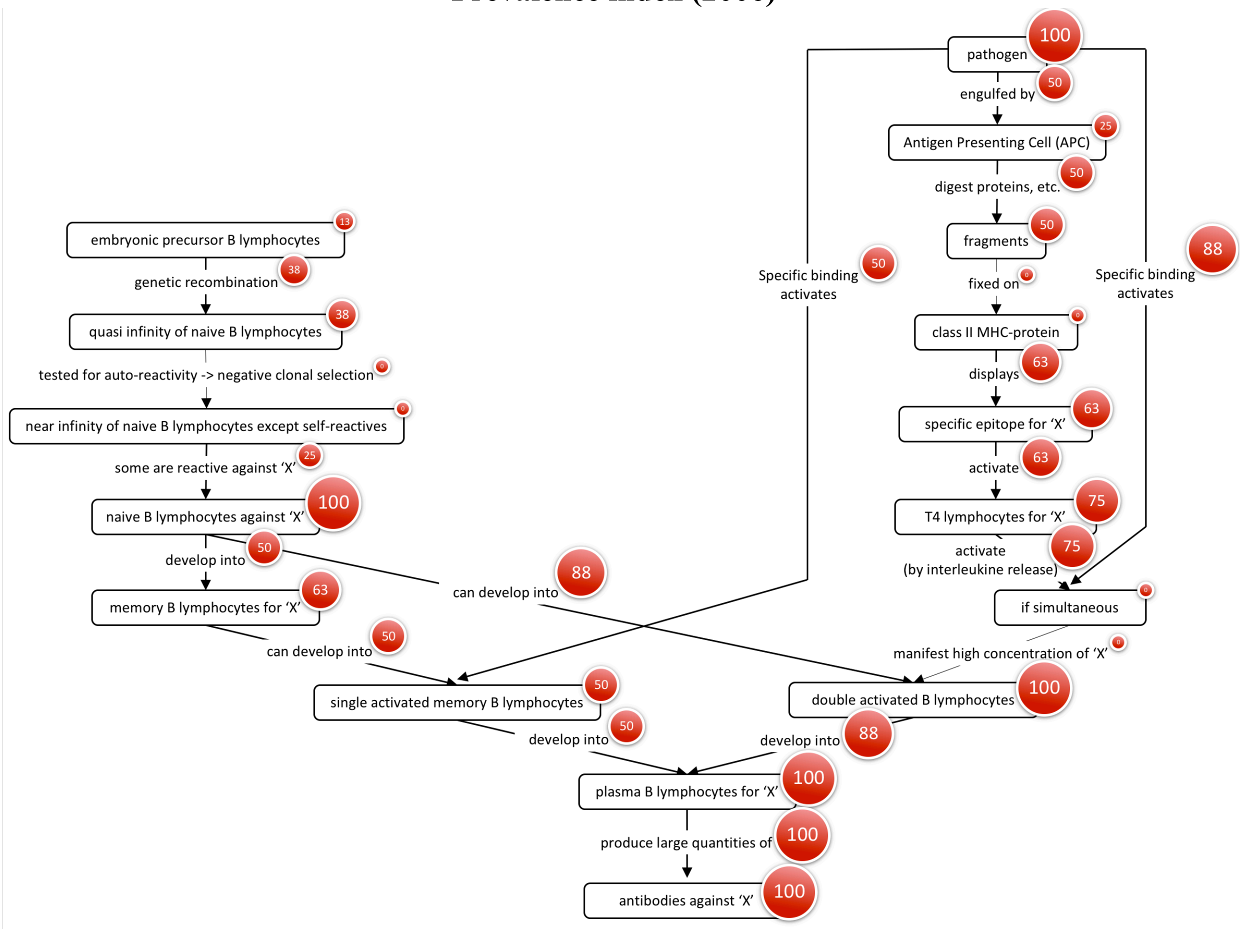

Figure 5. Prevalence index computed for all versions (2006) reveals early and late appearing concepts / links. Prevalence index 0 indicates model items that student did not expressed at all that specific year.

DISCUSSION AND CONCLUSIONS

First, our results confirm that important – and rarely available - insight into conceptual development during inquiry can be produced by this method. Results of this exploratory study show i) a non-linear conceptual progression and ii) a messy, incoherent progression (or a coherence that eludes us). Preliminary multi-year comparison suggests this method can reveal iii) differences in progression both over years and between groups, and iv) common patterns distinguishing *early* and *late*-appearing concepts or links.

Our data suggests - at least in the context of this study - that learning is an iterative, messy, difficult to predict process, without clear beginning or end, nor identifiable path. Progress appears to happen by refining and linking small bits of knowledge in mosaic fashion. One might be tempted to draw a parallel between this iterative messy unpredictable process of learning and the process of science (Abd-El-Khalick, 2011; Giordan, 1994, Latour & Gille, 2001).

Being able to know that (non-linear) progression is happening, and that there are common patterns offer opportunities to better understand how conceptual understanding develops or does not. This allows enhancing teacher guidance and informing the design of better learning environments.

Firstly, these results argue for including instructional design elements that reveal to students incoherencies in their models (as expressed in activities) and design elements that help them fill in gaps in causal chains. Also, these results highlight the potential of designs built around interactively improving a conceptual artifact (Bereiter, 2002; Scardamalia & Bereiter, 2006) to develop scientific understanding.

The data presented here along time in Figure 4 and Figure 5 shows that some model items form local causal chains early in the investigation process and others are completed much later, towards the end of the inquiry sequence.

Second we explore why some of the most crucial concepts do not appear until late or not at all (prevalence index 0) for year 2006 (e.g. simultaneous double activation of B cells by specific binding of antigen and T4 cells presenting the same specific epitope, negative clonal selection producing B-cell clones reactive against a near infinity of antigens except self and the presentation of antigen fragments by class II MHC proteins).

Third, looking again at which concepts / links appear early or late, we searched for evidence of conceptual obstacles (Bachelard, 1947) that would render some concepts or links difficult to understand. Coley and Tanner (2015) propose that cognitive construals could explain many misunderstandings in learning biology. We would therefore expect concepts that go against those construals to appear later. It could be argued in this light that clonal selection goes against a finalistic and animistic view of explanation and that would explain the late appearance of these model items and low prevalence index on Figure 5. Other late appearing concepts could be discussed similarly.

This method could be used over many years to search for stronger evidence of such late appearing concepts. Some preliminary results suggest this is the case.

Finally, we explored if this method could help reveal threshold concepts (Meyer, et al., 2010) since their understanding opens the door to understanding several other concepts. We would expect them to appear later and systematically precede the appearance of a group of links and concepts. We have not been able to demonstrate this clearly without over-interpreting.

Our results stress the importance of highlighting inconsistencies and gaps in the causal chain of students' explanations of phenomena and of organizing activities to fill them and lead students toward effective predictive and explanatory models. The relevance to modern biology seen as explanations – causal links – underpins this analysis, in particular in the perspective of conceptual change, student model confrontations, and teacher training.

Within its limits, our data suggests that science learning of complex phenomena is a non-linear process in which learners iteratively construct or transform a model. The implications for education are important: We could speculate, that in learning situations where learning is organized in linear process, only those students that are capable of processing iteratively what is presented - during instruction itself or while revising - learn efficiently. This would imply that only students with good self regulation of their learning processes benefit from linear designs such as lectures, some very linearly guided lab work or even some form of inquiry that requires students to follow a given path. This view of learning as iterative idea improvement is supported by much research in the knowledge building community: e.g. Scardamalia & Bereiter (2006). However, the relevance of our results -produced in an inquiry design designed around iterations of knowledge building - is a matter open to discussion and needs further research.

This interpretation might be seen as challenged by centuries of successful learning in teaching formats such as ex-cathedra courses that appear to be linear. We speculate that good learners have the skills to perform alone (during the course or revisions) these conceptual iterations in order to develop coherent usable models. We could define “deep learning” as capacity of using a given institutionalized model (Jungck, 2011) for prediction or explanation, not just repeating a given description of the model (also referred to as mastery goals rather than performance goals (Darnon, Muller, Schrager, Pannuzzo, & Butera, 2006)). The need for repeated iterations to attain such goals is also well highlighted by some literature: to organize learning as a knowledge improvement process (Scardamalia & Bereiter, 2006).

On a more practical side, this method could inform how we design for i) student awareness of conceptual gaps, ii) student drive towards knowledge improvement (completing causal chains), iii) focus on the model items of the model iv) how we structure iterations for that progression.

Our second research sub-question was about the factors that might orient student’s conceptual development. We mentioned the design (including teacher attitude, rules, assignments, etc.) cognitive constraints that might hinder or facilitate some type of explanations, "cognitive construals" (Coley & Tanner, 2015) and the resources students use – in which the epistemological structure of the conceptual field is embedded. We have suggested elsewhere (Lombard, 2012) that there might there be some sort of *conceptual centripetal force* in the resources and scientific paradigm of the field driving student progression towards some concepts and links that are central in our current understanding of immunology. While the sequence of model items appearance that this method reveals has offered some insight, methodological difficulties have till now prevented us from dissecting these factors orienting student progression. We have to leave this fascinating field of exploration open.

Whatever the causes, the repeated late appearance of some causal chains has implications on pedagogical design and guidance. The late – but systematic - appearance of the most important concepts (structuring concepts) opens venues of research: what design features or epistemic structure of the knowledge body can contribute to guide student progression towards these concepts? This could be useful in very different pedagogies. In a direct instruction view, for example, this method offers critical data to inform how we organize learning advancing from concepts we have found to be *early-appearing* towards late - probably difficult - concepts that are more fundamental. Indeed teachers’ perception of difficulties does not always reflect difficulties students encounter – especially about recent scientific advances (Yarden, Norris, & Phillips, 2015).

Overall potential for educational methods could include i) developing designs around a conceptual map of the model for institutionalizing ii) organize discussion of learning objectives by policy makers or teachers iii) identifying learning difficulties to prepare activities, questions, resources for helping students overcome these conceptual hurdles in completing causal chains iv) guidance during activities by visualizing the conceptual: field teachers might track conceptual progression and understanding gaps in order to raise questions, offer resources, at the appropriate time.

However establishing a conceptual map takes time and is likely to be seen as too demanding by many teachers and opens again a discussion on sharing designs within teacher communities. It could be argued that the need to define clear learning objectives takes time anyway.

The presented framework has some limits. One limit of time-related analysis of student productions is that students only write in the wiki when required to do so for an assignment such as presentation to peers or assessment of the page, etc. So written production probably lags behind the understanding progress; students may have acquired concepts or links but only write them some time later, possibly at the same time as other concepts that became easy to understand by passing this conceptual threshold. Writing might reveal previous progression in conceptual spaces and but not the exact time of the transition, and limits interpretation of time sequences.

Another fundamental limitation stems from our coding and data analysis method: analysis of text by searching for a given set of model items cannot reveal other concepts that might be present in student texts. It also presents the results in a more cognitivist manner than we would have liked. It doesn't show to which extent the learners were capable of *using* that model to explain or predict phenomena. We have discussed elsewhere (Lombard, 2012) evidence showing that they did so. However we would like to argue that the unusual detail in conceptual progression and long-term comparison revealed by this method seem worth this limitation.

The scope of our analysis is also limited by the small sample and the single investigation design in which they were established. While it is tempting to think that these results have a broader scope, it is probably reasonable to consider them as exploratory and we are currently developing this research into this data set for other years and other subject questions. It would be interesting to explore it in other settings and with larger samples. A challenge will be to get this type of relevant traces of conceptual learner progress in other learning designs than wiki-supported IBL. With the increase in technology supported learning this will probably become easier.

With data accumulating we hope to find ways to dissect the i) effects of learner difficulties such as cognitive construals, ii) weaknesses of designs or iii) epistemic specificities of the knowledge structure in experiments and resources used by students.

REFERENCES

Abd-El-Khalick, F. (2011). Examining the Sources for our Understandings about Science: Enduring conflations and critical issues in research on nature of science in science education. *International Journal of Science Education, 34*(3), 353-374.

Bachelard, G. (1947). *La formation de l'esprit scientifique*: Vrin Paris.

Bereiter, C. (2002). *Education and Mind in the Knowledge Age* (Second ed.). Mahwah, New Jersey, United States: Lawrence Erlbaum Associates.

Biggs, J. (2003). Aligning teaching for constructing learning. *Higher Education Academy*.

Brousseau, G. (1998). *Théorie des situations didactiques*. Grenoble: La pensée sauvage.

Brown, A. L. (1992). Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *The Journal of the Learning Sciences, 2*(2), 141-178.

Coley, J. D., & Tanner, K. (2015). Relations between Intuitive Biological Thinking and Biological Misconceptions in Biology Majors and Nonmajors. *CBE-Life Sciences Education, 14*(1), ar8.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design Research: Theoretical and Methodological Issues. *Journal of the Learning Sciences, 13*(1), 15-42.

Darnon, C., Muller, D., Schrager, S. M., Pannuzzo, N., & Butera, F. (2006). Mastery and Performance Goals Predict Epistemic and Relational Conflict Regulation. *Journal of Educational Psychology, 98*(4), 766.

Giordan, A. (1994). *L'élève et/ou les connaissances scientifiques*: P. Lang.

Jungck, J. R. (2011). Mathematical Biology Education: Modeling Makes Meaning. *Mathematical Modelling of Natural Phenomena, 6*(6), 1-21.

Latour, B., & Gille, D. (2001). *L'espoir de Pandore: pour une version réaliste de l'activité scientifique*: La Découverte, Paris.

Lombard, F. (2012). *Conception et analyse de dispositifs d'investigation en biologie : comment conjuguer autonomie dans la validation scientifique, approfondissement conceptuel dans le paradigme et couverture curriculaire ?* Doctorat Doctorat, Université de Genève, Genève.

Lombard, F. E., & Schneider, D. K. (2013). Good student questions in inquiry learning. *Journal of Biological Education, 47*(3), 166-174.

Martinand, J. L. (1996). *Introduction à la modélisation*. Paper presented at the Actes du séminaire de didactique des disciplines technologiques., Cachan Paris

Meyer, J. H. F., Land, R., & Baillie, C. (Eds.). (2010). *Threshold Concepts and Transformational Learning* (Vol. 16). Rotterdam: Sense Publisher.

Morange, M. (2003). *Histoire de la biologie moléculaire* (2ème edition)Paris: La Découverte.

Novak, J. D., & Cañas, A. J. (2008). The theory underlying concept maps and how to construct and use them. *Florida Institute for Human and Machine Cognition, 2008*.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 97–115). New York, USA: Cambridge University Press.

Tiberghien, A. (1994). Modeling as a basis for analyzing teaching-learning situations. *Learning and instruction, 4*(1), 71-87.

Weber, M. (2009). *The Theory Of Social And Economic Organization*: Simon and Schuster.

Wiggins, G., & McTighe, J. (2000). *Understanding by Design*. Upper Saddle River, NJ:: Prentice Hall.

Yarden, A., Norris, S. P., & Phillips, L. M. (2015). Applications of Adapted Primary Literature *Adapted Primary Literature* (pp. 125-142): Springer.

Zabel, J., & Gropengiesser, H. (2011). Learning progress in evolution theory: climbing a ladder or roaming a landscape? *Journal of Biological Education, 45*(3), 143-149.

EFFECT OF PEER DISCUSSIONS, AS PART OF FORMATIVE ASSESSMENT, ON LEARNING OF PHYSICS CONCEPTS

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Abstract: We developed a model of formative assessment and applied it to concept leaning in Physics at Swiss high schools. To study the effect of formative assessment we recruited 30 teachers and divided them into three groups with at least 10 classes each. The groups formed are the experimental group with the formative assessment approach and two control groups. The first control group just applied tradition teaching without any instructional restrictions. The second control group was introduced to account for the effect of frequent testing. This group solved all the tests of the formative assessment group but not in the formative assessment approach. The goal of this work is to identify elements of our formative assessment approach, which promote learning of physics concepts. The major differences between solving concept questions as test questions or as clicker questions are peer discussions and classroom discussions. Therefore we compare in this study the formative assessment group to the frequent testing group. To estimate students' concept knowledge before and after the teaching sequence we developed a kinematics concept test, which we used as pre- and post-test. The topic taught during the teaching sequence was kinematics for which we have identified seven concepts. Our analysis revealed that after peer discussions the formative assessment group outperforms the two control groups in the post-test with respect to all seven concepts.

Keywords: formative assessment, peer instruction, peer discussion, clicker questions, concept learning

INTRODUCTION

In their seminal paper Paul Black and Dylan Wiliam (Black & Wiliam, 2009) defined five key strategies of formative assessment. We have used these strategies to develop a model of formative assessment, which can be used in classroom teaching. Our approach (Wagner & Vaterlaus, 2012) encompasses four different tools (see Figure 1). First, classroom activities (1) were designed in order make student concept knowledge visible and to elicit student learning. The activities consisted of two clicker sessions with 15 concept questions each. The procedure, of applying clicker question to students, was mainly borrowed from peer instruction suggested by Eric Mazur (Mazur, 1997). Second, we developed a monitoring tool (2) where students monitor their learning progress. The monitoring tool contains diagrams with the temporal evolution of students' concept knowledge based on the self-assessment of clicker questions. Due to the fact that peer discussions are central to clicker questions students are used in these discussions as instructional resources. In the middle of the teaching sequence a lesson was dedicated to the diagnostic tool (3). Although students and teachers already get feedback during clicker sessions we thought that an independent, more detailed and individual feedback from an independent source might be necessary. Thus, the diagnostic tool not only analyses concept knowledge of students but also misconceptions, which still might be present. The students can also compare the results from the diagnostic tool to the learning progress recorded with the monitoring tool to verify the validity of their self-assessment. The feedback of the diagnostic tool for the teacher contains the average performance of the class. He has no information about the individual feedback to the students. The application of the diagnostic tool always has to be followed by a reflective lesson (4). Due to the detailed feedback from the diagnostic tool students must get the opportunity to work on their deficits and to catch up. The teacher uses the information from the diagnostic tool to prepare this lesson. He or she offers students different learning activities based on the analysis of the diagnostic tool. Students then have to choose from the learning material the concepts they would like to work on. We think that the choice now students have shifts the responsibility of learning to a certain degree to the students' side.

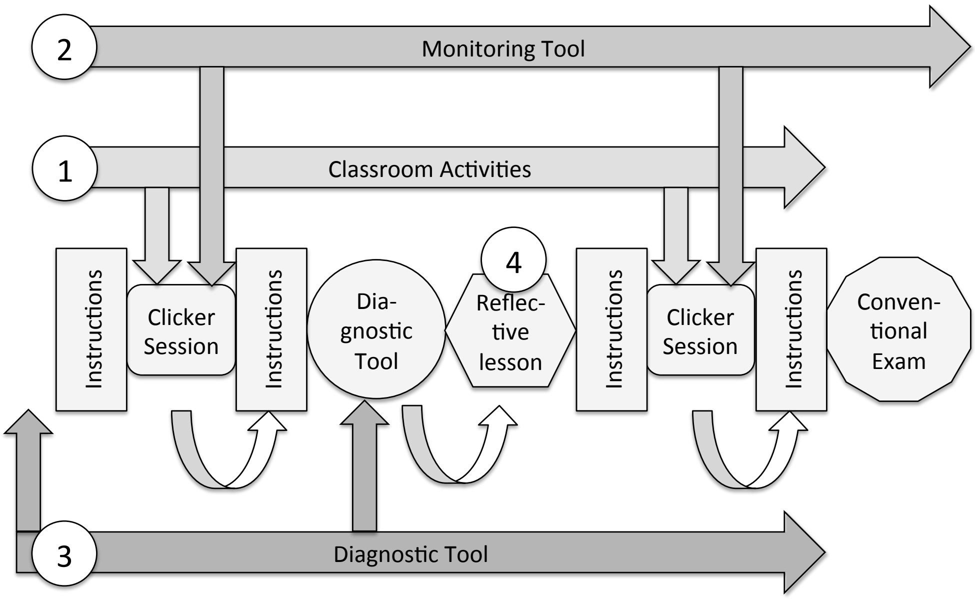

Figure 1. Model of formative assessment using four different tools 1. Classroom activities (clicker sessions), which elicit evidence of student learning. 2. Monitoring tool to record students' learning progress. 3. Diagnostic tool (DT) to give students a detailed individual feedback about their concept knowledge and their misconceptions. The diagnostic tool could also be used to estimate the pre-knowledge. 4. Reflective lesson where students have the opportunity to catch up.

The Study

Since the development of the force concept inventory (Hestenes, Wells, & Swackhammer, 1992) the shortage of conceptual knowledge in physics has been stated in many countries (Hake, 1998) including Switzerland. Thus we devised a project to foster concept knowledge using our model of formative assessment. The topic for the implementation was kinematics. We recruited 30 teachers from Swiss high schools for the project. They were randomly assigned to the experimental group and the two control groups. All teachers received a half-day information how to do the tests and to process the results. Teachers from the formative assessment group had an additional half-day in order to learn how to conduct clicker sessions and to plan a reflective lesson for which they received additional teaching material. However, they were also encouraged to develop their own material to adjust teaching to the needs of the students.

As mentioned above the traditional teaching group received only a list of the content. It was in their responsibility how to distribute the content among the 14 lectures, which were at their disposal. We asked them to teach the material in the way they are used to. In contrast to this traditional teaching group (TT-group) the formative assessment group (FA-group) had only 10 lectures for the regular teaching. In addition, they had to conduct two clicker sessions (2 lessons), a diagnostic test (1 lesson) and a reflective lesson (1 lesson). We expected that the deeper conceptual knowledge would compensate for the diminished time on solving conventional problems. Finally the second control group, the frequent testing group (FT-group), had approximately two lessons less than the TT-group. Students from the FT-group solved the clicker questions at the computer, for which in the average only half a lesson was used (2 x ½ lesson). Teachers of the FT-group were asked not to discuss the problems with the students. However, if a student asked the teacher after the session for an explanation of a problem they were allowed to answer the question. The FT-group also did the diagnostic test (1lesson) but the reflective lesson was missing. Thus the extra test time sums up to about two lessons. Finally, all three groups finished the teaching phase with a conventional test during the 15th lesson. The design of the study is presented in Figure 2.

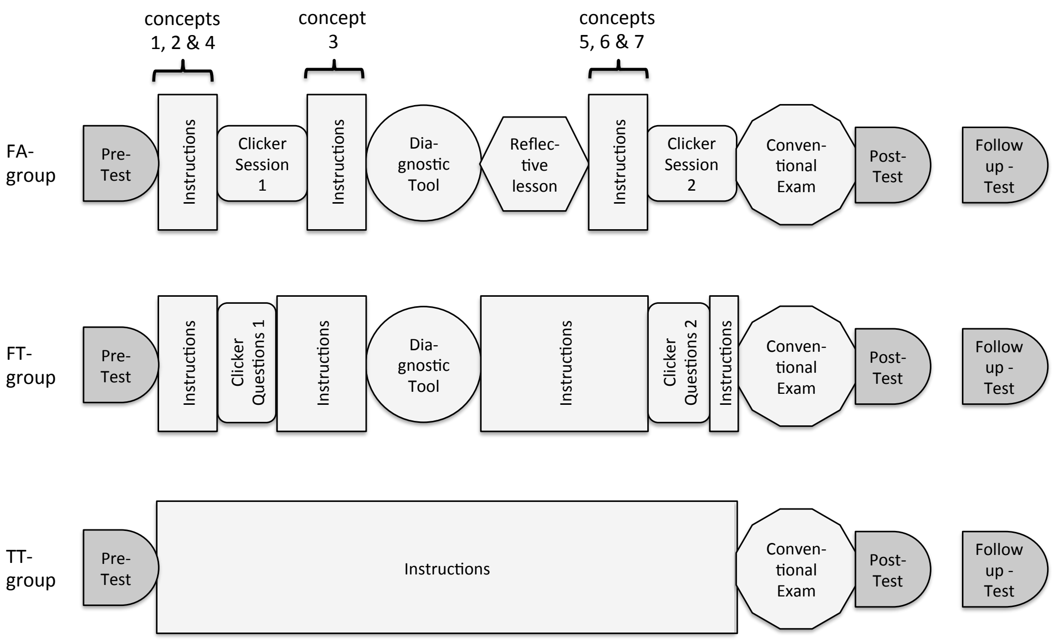

Figure 2. Design of the Study. Teachers were randomly assigned to the traditional teaching group (TT-group), the frequent-testing group (FT-group) and the formative assessment group (FA-group). All teachers were basically free to design their instructions except for compulsory tests and the reflective lesson indicated. The diagnostic tool (DT) is followed by the reflective lesson and the teaching sequence is completed by a conventional test.

We have identified seven concepts for the content covered in kinematics. These are

1. Velocity as rate.
2. Velocity as one-dimensional vector.
3. Velocity as two-dimensional vector.
4. Area under the v,t-curve as displacement.
5. Acceleration as rate.
6. Acceleration as one dimensional vector
7. Area under the a,t-curve as velocity change.

In the FA-group as well as in the FT-group concepts 1, 2 and 4 were taught during the first four lessons since they were included in the first clicker session. Lessons 6 and 7 were reserved for concept 3. Thus the diagnostic test provided feedback for the students about concepts 1 to 4 and the corresponding misconceptions. In lesson nine the reflective lesson takes place followed by 4 lessons, which discuss concepts five to seven about acceleration. Lesson 14 is reserved for the second clicker session testing for concept 3, 5, 6 and 7.

We have developed a kinematics concept test in order to assess concept knowledge of students. It consists of 54 multiple-choice questions, which cover the physics concepts defined below. The test was validated in the usual way (Lichtenberger, Wagner, & Vaterlaus, 2015) and used as pre-, post- and follow up test.

The major results of our study are that first the FA-group outperforms the two control groups with respect to concept knowledge and second the performance of the three groups considering the conventional test doesn't reveal any significant difference (Lichtenberger et al., 2015). In this work we follow the question why does the FA-group show higher conceptual knowledge than the control groups? It seems to be clear that the traditional teaching group performs worst on conceptual problems since they were not trained in answering this type of questions. The fittest group answering clicker questions is the frequent testing group. As already mentioned clicker sessions consist of 15 questions. Since students from the FT-group solved these questions on the computer, with an immediate feedback if their answer is right or wrong, the time to solve all 15 problems was about 20 – 25 min. However, due to the procedure of conducting clicker questions in the FA-group, which includes peer discussions, the time of the lesson lasted only for 6-12 problems in the FA-group. From this point of view on might be tempted to assume that the FT-group performs best on conceptual tests. As mentioned above our data revealed a different picture, namely that the FA-group performs best on the conceptual test, this not only on the post-test but also on the normalized gain (Lichtenberger et al., 2015).

METHODS

In general formative assessment can assume many different forms including on the fly feedback. However, in particular the latter is difficult to control since all teachers in Swiss high schools do it by some means or other. Thus, in our project we restricted ourselves to a single method, which we called clicker session. It is just a sequence of multiple-choice concept questions administrated to the students using a well-defined procedure. The goal of these questions is that students have to apply the concepts to problems presented in different contexts. The distractors should provide space for small group peer discussions. From that point of view the clicker problems are quite different form the kinematics test questions since their distractors have to be directly linked either to a concept or a single misconception. The answer of a clicker question might involve several concepts at the same time. However, it was always possible to assign a major concept to the question. The assignment of concepts to questions was verified by several experts.

The success of clicker questions in teaching at the college level has been shown by many research groups. C. Crouch and E. Mazur (Crouch & Mazur, 2001) analyzed data from 10 years and observed in calculus and algebra based courses a significant increase in conceptual knowledge. Moreover, they also find that an increase in solving quantitative problems. Smith and coworkers (Smith et al., 2009) also report a successful application of peer instruction. They show convincingly that the increase of concept knowledge through peer discussion can be assigned to real learning.

Clicker Sessions

The procedure used to administrate the questions to the students follows the ideas of Peer Instruction (Mazur, 1997). Peer instruction can be implemented in different configurations, which all are nicely summarized in a review by Vickrey et al. (Vickrey, Rosploch, Rahmanian, Pilarz, & Stains, 2015). In our case the implementation can be divided into three well-defined phases (see Figure 3). Having presented the MC-question via a projector all students answered the question individually. They protocol their choice in their monitoring tool. Moreover, they also have to assign a concept to the question. If students would have to justify their answer they would use this concept in their argumentation. This silent phase is finished when the students have sent the answer to the receiver using their clicker device. After the first phase a histogram of the answers is presented to the students. It serves as a delimiter of the silent, individual phase and the discussion phase. It also should motivate students to reflect about their first answers. The second phase opens the question to groups of three. Students discuss the problem in order to convince each other using the concept selected in the previous phase. The answers are collected for the second time and the data is again presented in a histogram. This marks the end of the second phase. During the last phase the question is discussed in class. One possibility is to ask one of the groups to share their results of the discussion with the class and to explain the solution using one of the given concepts. However, it is also interesting to discuss in class why some of the distractor are not possible. Moreover, the teacher should be able to use spontaneously additional examples or variations of the given problem for further clarification.

In order to control whether this clicker sessions are conducted properly we sent to all lessons university students (mainly psychology majors) to monitor the sessions. For all questions they recorded the time for the individual and the group answer as well as for the classroom discussion phase. In additions two groups of each session were recorded using a microphone. Thus we got a good impression, what was going on in these classes. We haven't yet looked at the data but they will be used in further analysis. However they would have been a good resource if anything went wrong with the experimental group.

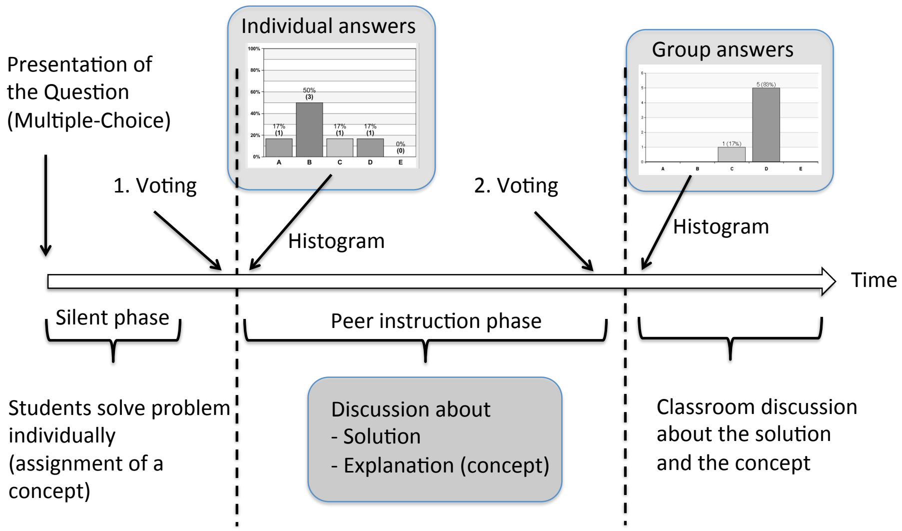

Figure 3. Procedure of a clicker question. The clicker question is divided in three different phases: an individual phase, where students answer the question individually, a peer discussion phase, where the problem is discussed in groups of three students and classroom discussion phase, where the teacher discusses the problem with the students.

Teachers from the formative assessment group used the clicker system from Turning Point to conduct the clicker sessions. The students got an individual clicker device where the number of the clicker was uniquely linked to the student's code. Thus, we can track student's performance (individual and group answers) during a clicker session. All answers were recorded and stored in an excel file, which the teacher had to send us.

This triple, individual answer, small group discussion and sharing the ideas with the whole class, seems to be a very general method in order to apply formative assessment successfully. In 2008 Yue Yin et al. (Yin et al., 2008) reported of a formative assessment approach applied to middle school pupils in the framework of embedded formative assessment (FAST). The goal was to improve conceptual change in a sinking and floating teaching sequence. However the authors do not observe a positive effect of formative assessment on conceptual change. In contrast, a few years later and also in a smaller study when Yin et al. (Yin, Tomita, &

Shavelson, 2014) used the threefold approach a significant increase of conceptual change was observed.

In order not to slow down artificially the clicker sessions the teacher were furnished with a set of rules how to move on after the first vote. For example, if 90% of the answers were correct after the first vote it doesn't make sense to organize a group discussion and a second vote. In this case teachers were advised to skip the peer discussion phase and move directly to the classroom discussion. The set of rules is given in Table 1.

Table 1. Rules for conducting clicker sessions. The first column shows the result of the first vote and the second column presents how the teacher should react and continue.

Percentage of correct answers	Continuation
< 10	- one wrong distractor selected by a majority: teacher tells the students that this answer is wrong and that they should discuss, which of the other answers might be correct. - wrong answers are distributed equally among the distractors: Teacher tells the students what the correct answer is that they should discuss what concept fits to this answer.
10 - 30	Depending on the actual impression of the teacher, he decides whether it might be worth to organize the peer discussion.
30 - 70	best range for a peer discussion
70 - 90	Depending on the actual impression of the teacher, he decides whether it might be worth to organize the peer discussion.
> 90	Skip the peer discussion and move on to the classroom discussion

For the students of the frequent testing group we have set up a survey using the lime survey program on one of our servers. All clicker questions were then adapted to the system and programmed accordingly. Students only had to chose an answer and not one of the concepts. They also didn't have the list of concepts. Having chosen an answer, students got a feed back if the answer was right or wrong. If the answer was wrong, the correct answer was highlighted. With the help of the feedback we expect that some students develop strategies to solve this type of problems, moreover some students will also attain a certain degree of concept knowledge by combining the feedback with the content of the teaching lessons.

RESULTS

In this paper we compare the results of students where clicker questions were either posed using the formative assessment approach (FA-group) or solved at the computer (FT-group). The goal is to draw conclusions about the effectiveness of clicker questions with or without formative assessment on learning of concepts in physics.

The first Clicker session took place after four lessons and included concepts 1, 2 and 4. Some classes of the FA-group only worked on six of the 15 problems during the clicker session. The problems are distributed among the concepts so that all three concepts are covered by two questions within the first six questions. Thus, concept knowledge was estimated from the first 6 questions of the session. Although the FT-group solved all 15 questions we have considered also for the FT-group only the first six question for reasons of comparison.

The results of the first clicker session of the FA-group and the FT group are shown in Figure 4. Comparing the percentage of correct answers for the three concepts of the FT-group with the answers of the FA-group one can recognize that the values for the individual answer of the FA-group is in the range of the values of the FT-group. We conclude that in the teaching phase before the clicker session there was no special focus on the development of conceptual knowledge in the FA-group. We are going to further study this issue since we have all the teaching materials and the teacher protocols of the lessons.

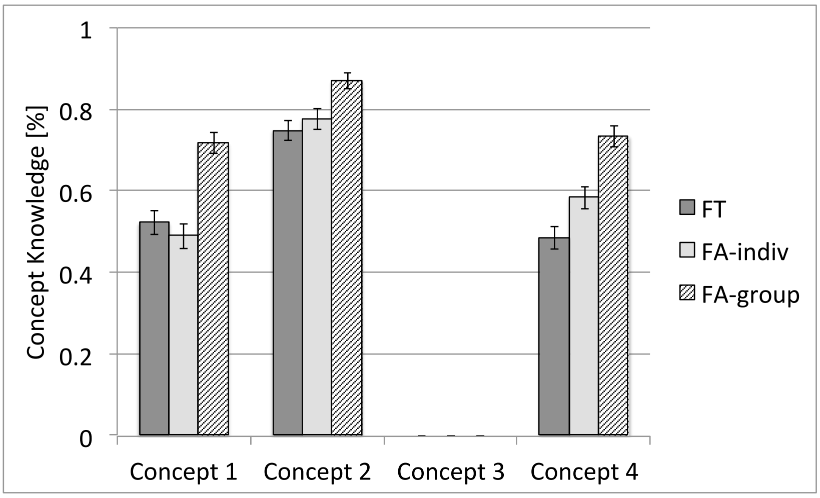

Figure 4. Results of clicker session 1. The bar graph shows the percentage of correct answer versus concept number of the first six question of the clicker session (two questions per concept). The first, second and third bar of each concept corresponds to the answers of the FT-group (173 students), the individual answer of the FA-group and the group-answer of the FA-group (154 students).

However, if we compare the result of the group-answer of the FA-group with the individual answer and the answer of the FT-group then we observe a marked increase for concepts 1 and 4 and a minor augmentation of concept 2. The latter might be due to the fact that concept 2 is easier for the students to understand than the others. What we see here is a saturation effect. Often there was no peer discussion for concept 2 questions and therefore no group-discussion took place due to our recommendations given in Table 1. In these cases we took the group answer equal to the individual answer.

There might be two explanations for the increased level of the group answer compared to the level individual answer. First, lower ability students of the group just adopt the answer of the best student in the group. In this case no learning occurs and in concept test student from the FA-group would perform equally as students from the FT-group, since the results were comparable for the individual answer. In contrast, if during the peer instruction phase and the classroom discussion phase real learning takes place the students of the FA-group is expected to perform better in a concept test.

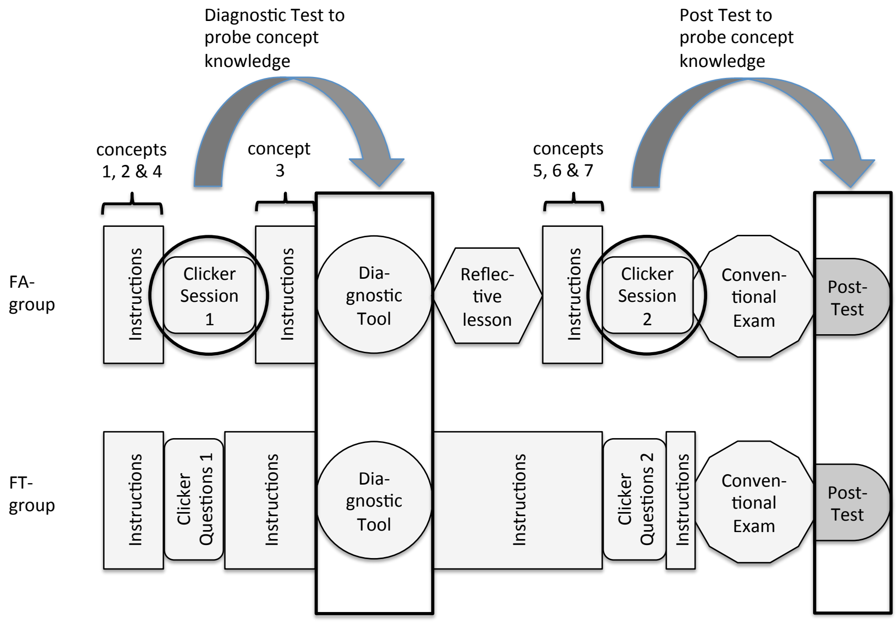

Figure 5. The diagnostic test (Diagnostic Tool) and the post-test were used to probe the effectiveness of the formative assessment approach. In clicker session 1 and clicker session 2 of the FA-group (thick circles) the FA-approach was used, while the FT-group solved the clicker questions at the computer.

In order to review the effectiveness of the first clicker session within our formative assessment approach we used the diagnostic test. It was applied to the students after having taught concept three and thus comprises concepts one to four. Questions of the diagnostic test are similar to questions of the kinematics concept test. The test is composed of 33 questions and solved at the computer. The results are shown in Figure 6.

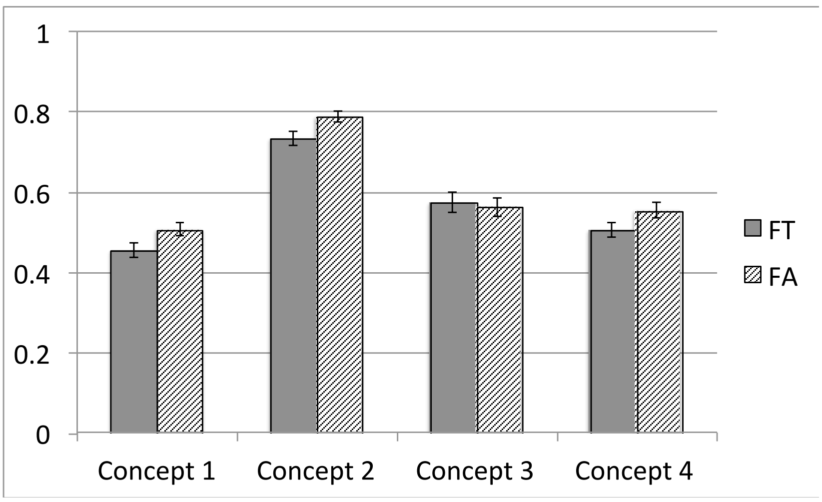

Figure 6. Results of the diagnostic test. Regarding concepts 1, 2 and 4 the FA-group (199 students) outperforms the FT-group (167 students). The *p*-levels for concepts 1, 2, and 4 are 0.028, 0.014 and 0.074, respectively. For concept 3, which was taught after the first clicker sessions, no significant difference between the performance of the FA- and the FT-group was found.

For the three concepts, which were included in the first clicker session the FA-group outperforms the FT-group. We used ANOVA to estimate the significance. For concept 1, 2 and 4 the *p*-values are 0.028, 0.014 and 0.074, respectively. Since the performance of the two groups are equal in the pre-test, we assign the increased knowledge of the FA-group compared with the FT-group to the peer discussions and the classroom discussions where students are used as instructional resources. The exception is concept three where the two groups cannot be distinguished anymore. Our explanation for this fact is, that concept three was taught after the clicker session so that no discussions about this concept have taken place. Of course, it was interesting to see how concepts three evolves further during the experimental phase.

In order to verify the hypothesis that peer discussions might be essential for learning Physics' concepts we started to investigate the second clicker session. It examines concepts 3, 5, 6 and 7. Again, the FT-group solved the problems at the computer with a short feedback about the correctness of the answer. In the FA-group we used our formative assessment approach. The results of clicker session two are displayed in Figure 7. Teachers from the FA-group were able to discuss six to twelve questions with the students. In order to have as many students as possible in the analysis we used the first seven questions to analyze concept knowledge. Concepts 3, 5 and 6 are covered by two questions whereas concept 7 is represented by only one question. We have estimated the concept knowledge of the FT-group once with the first seven questions and once with all 15 questions. There was almost no difference. Therefore we assume that the analysis of the first seven questions is a good estimate of the concept knowledge. Due to the condition that at least seven questions had to be discussed we lost several classes and the number of students of the FA-group was reduced to 98.

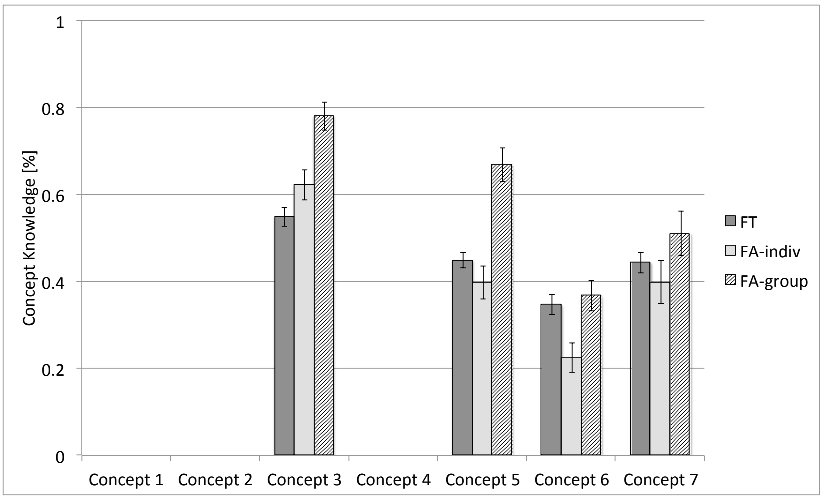

Figure 7. Results of clicker session 2. The bar graph shows the percentage of correct answer versus concept number of the first seven question of the clicker session 2. The first bar of each concept represents the FT-group (196 students) whereas the second and third bar is from the individual and from the group answers of the FA-group (98 students).

Despite the reduction of the sample size we obtained quite similar results as for clicker session one. Except for concept 6 the individual answers of the FA-group and the answers of the FT-group reach similar values. Our second observation was that the levels of the group-answer (FA-group) is always higher than the answer levels of the FT-group. Although the differences for concepts 6 and 7 are not statistically significant the tendency is clearly recognizable. The last observation that the level of the group-answer is always higher than the level of the individual answers of the FA-group holds for all four concepts.

In order to check whether this increase in the group-answer of the FA-group is due to real learning or not we compare the FT-group to the FA-group in a separated and independent test. As shown in Figure 5 we used the kinematic concept test as control. The results are presented in Figure 8.

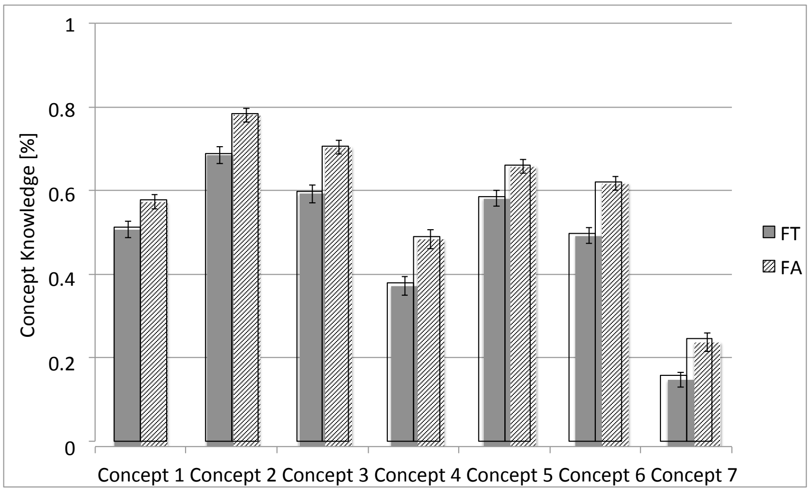

Figure 8. Results of the post kinematic concept test. In all seven concepts the FA-group (191 students) outperform the FT-group (194 students). The statistical significance given by the *p*-values are 0.0118, 0.0006, 0.0001, 0.0005, 0.0038, 0.0000, 0.0014 for concepts 1, 2, 3, 4, 5, 6 and 7, respectively

In all seven concepts the FA-group now prevails. The statistical significance determined by ANOVA is given by the *p*-values 0.0118, 0.0006, 0.0001, 0.0005, 0.0038, 0.0000, 0.0014 for concepts 1, 2, 3, 4, 5, 6 and 7, respectively. We remember that in the diagnostic test (Figure 5) the concept knowledge for concept three of the FA-group and the FT-group were similar. However, after clicker session two, which includes questions about concept three, the results of the FA-group in the post-test are now significantly higher than that of the FT-group (Figure 8).

DISCUSSION

We have developed a model of formative assessment and applied it to concept learning in Swiss high schools in Physics. The model consists of four different elements, first classroom activities, which are designed to learn Physics concepts and which elicit evidence of student learning, second, a monitoring tool where students protocol their progress, third, a diagnostic tool in order to give feedback to the students about their actual knowledge and to the teacher about the performance of the class and fourth, a reflective lesson where students have the opportunity to work on their deficits.

This formative assessment approach was administrated in Swiss high schools to learn concepts in kinematics (see Table 1). We recruited 30 teachers and divided them into three groups, the experimental (FA-) group using the full model of formative assessment, a traditional teaching (TT-) group as control group to evaluate the overall learning gain and a second control group the frequent testing (FT-) to estimate the effect of solving the same set of problems but not in the formative assessment approach. As presented in Figure 8 the FA-group outperforms the FT-group regarding all concepts taught during the teaching phase.

In this paper we asked the question why this is the case. Due to the fact that several tools are involved in our formative assessment approach all of them might contribute to the success of the experiment. One question arises first, namely, are the questions of the clicker sessions effective or not. Therefore we compared the results of the formative assessment group to the results of the frequent testing group. We observe that the individual answer of the FA-group is in the range of the result of the FT-group. Our interpretation is that the teachers of both groups prepared their teaching material in a similar way, mainly as before maybe with a few adjustments to the new schedule. Therefore we believe that a better design of the teaching material focusing on the application of the concepts would lead even to a better result.

However, since we have collected all teaching material and teaching protocols we are going to investigate this question further.

A step up of concept knowledge of the FA-group can be observed after the peer discussions in both clicker sessions. Whether this increase is just artificial or if it reflects real learning is another issue we intended to investigate. Since the FA-group and the FT-group had the same initial average values for all concepts (data not shown) the increase in conceptual knowledge has to be explained by the teaching phase between the pre- and the post-test. The increase from the individual answer to the group answer in the FA-group is quite drastic. We believe that this increase has two contributions: first, some students indeed learn how to apply and to work with these concepts from the discussions and second some students adopt the answer of the best student in the group if they are not sure about their own argumentation. However, the part of students who really learn the concepts is big enough that it becomes statistically significant. This is shown in the diagnostic test (Figure 6) as well as in the kinematic concept test (Figure 8).

Concept three is a special concept regarding its position in the time course. It is not included in the first clicker session (Figure 4). It is taught after clicker session one and becomes part of the diagnostic test where the performance of the FA-group and the FT-group revealed no difference (Figure 6). We assume that the equal performance of the two groups can be explained by the fact that no peer discussion about concept three has taken place before the diagnostic test. If we compare the individual answer of the FA-group with the level of the FT-group in the second clicker session we see that FA-group already outperforms the FT-group. This sudden increase might be explained by the reflective lesson, which had followed the diagnostic test. There, students with a low knowledge of concept three had the opportunity to work on it. Thus the increase in concept knowledge at least of concept one to four might not be exclusively assigned to peer discussions since it includes other elements of our formative assessment approach. Moreover, the monitoring tool not only asks for the correct answer but also for the concept associated with that question. Therefore, students really had to deal with the concepts behind the problems. They also should learn that each problem can be solved by applying physics concepts properly.

In order to rebut the argument that the program of the FA-group was teaching to the test and that it is obvious that this group would outperform the TT-group we introduced the FT-group. Students from this group solved the same tests as the FA-group so that the differences are due to the formative assessment approach. Moreover, the FT-group solved all 15 questions of the clicker sessions whereas the FA-group solved only about eight in the average. The difference is that in the FT-group no peer discussions and no classroom discussions took place saving a large amount of time this way. Teachers from the FT-group were allowed to answer all questions from the students about the clicker questions, however it was not allowed to use them as instructional tool. Thus, one might conclude, that not the number of questions is relevant for learning but rather how the questions are applied to the students. In addition and as mentioned above the questions from the diagnostic test and the kinematic concept test are quite different from the clicker questions due to their different purpose. The clicker questions are designed in such a way that they provide space for discussions. In contrast, the questions of the diagnostic test and kinematic concept test focus on the unique assignment of the correct answers to a single concept and the distractors to a single misconception. Thus the construction of the questions is in most cases quite different.

In summary, we have presented a model of formative assessment and how it can be applied to concept learning in Physics. Our data revealed that indeed students learn concepts better in the framework of our formative assessment approach compared to traditional teaching and to frequent testing. One might argue that this result is obvious since the FA-group focuses on concept learning and disregards solving conventional problems. However, we also have controlled this variable and developed a conventional test with exclusively conventional, numerical problems. The interesting result was that all three groups performed equally on this test. This would be in line with our assumption that teachers of the FA-group did not really focus on concept learning during instructions. Concept learning mainly took place during the clicker sessions. Nevertheless it is remarkable that there is no difference in the conventional test between the groups since the FA-group had four lessons less for the same material as the TT-group (Figure 2). We think that the acquired concept knowledge helps students from the FA-group to transfer their knowledge to new problems. In this way they can compensate for the missing routine they have compared to students from the TT-group in solving conventional problems.

REFERENCES

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment Evaluation and Accountability, 21*(1), 5-31.

Crouch, C. H., & Mazur, E. (2001). Peer Instruction: Ten Years of Experience and Results. *American Journal of Physics, 69*(9), 970 - 977.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74.

Hestenes, D., Wells, M., & Swackhammer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141 - 166.

Lichtenberger, A., Wagner, C., & Vaterlaus, A. (2015). *A Comparison Study between Formative Assessment and Traditional Teaching in Kinematics at Swiss High School*. Retrieved from https://drive.google.com/folderview?id=0Bz5G1CUg6N1EfkxtR0NhZVk2T2oxS05BWnJQUDhkSXhKdmwyUW03QjRyZ255QVcxY3o4Z2s&usp=sharing

Mazur, E. (1997). *Peer Instruction: A User's Maual*. New Jersey: Pearson, Prentice Hall.

Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., & Su, T. T. (2009). Why Peer Discussion Improves Student Performance on In-Class Concept Questions. *Science, 323*(5910), 122-124.

Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M., & Stains, M. (2015). Research-Based Implementation of Peer Instruction: A Literature Review. *CBE-Life Sciences Education, 14*, 1-11.

Wagner, C., & Vaterlaus, A. (2012). Promoting Formative Assessment in High School Teaching of Physics. *Lat. Am. J. Phys. Educ., 1*, 410 - 415.

Yin, Y., Shavelson, R. J., Ayala, C. C., Ruiz-Primo, M. A., Brandon, P. R., Furtak, E. M., Young, D. B. (2008). On the Impact of Formative Assessment on Student Motivation, Achievement, and Conceptual Change. *Applied Measurement in Education, 21*(4), 335-359.

Yin, Y., Tomita, M. K., & Shavelson, R. J. (2014). Using Formal Embedded Formative Assessments Aligned with a Short-Term Learning Progression to Promote Conceptual Change and Achievement in Science. *International Journal of Science Education, 36*(4), 531-552.

EVOLUTIONARY THEORY: WHEN RELIGIOUS BELIEFS ARE NOT REMEMBERED

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Abstract: Researches in the teaching of Evolution indicate the association between origin and diversity of life and religious explanation. However, when students were encouraged to observe, record and analyze what they saw, there was no mention of religious explanation. In this work, we investigated: how far students would be committed to religious beliefs to explain the natural phenomena? For this, we identified and analyzed the social representations of students of the ninth year of elementary school and the third year of high school on the appearance of the first living being and the planet Earth about 4 billion years ago. The students belonged to a public school in the state of Rio de Janeiro, Brazil, with the absence of an infrastructure (laboratories, educational teaching resources and teachers) and located in a social context where churches, especially evangelical, had strong social and doctrinal action of the search context. The methodology used was the analysis of the Collective Subject Discourse (CSD). The speeches revealed that when asked about the phenomenon of life, the religious creationist explanations (the creation of Adam and Eve) were the most remembered. However, when asked about the conditions of the planet Earth about 4 billion years ago, that is, a world "without life", they remembered more about scientific explanations of evolution and the lack of technological artifacts that are present in today's world ("Electricity, homes, work, etc."). The present results suggest that, in the absence of religious references to natural phenomena, religious beliefs are not expressed. The results of this study allow us to highlight the importance of this scenario and the exercises for the students to practice science. In other words: when students learn through scientific procedures, such as observation, recording and analysis of phenomena, religious explanations are less expressed.

Keywords: science education; theory of evolution; social representations.

INTRODUCTION

Researches in the evolution's teaching (Costa et al. (2011), Rice & Kaya (2012) and Vieira & Falcão (2014)) indicated that the idea of the divine creation of species or "intelligent design" explanations are used to replace the "chance" concept in the evolutionary process.

Analysis of these results brings an issue facing teachers: the association between origin and diversity of life and religious explanation, which idea of an omnipotent creator would pervade in the Western World. However, when students were encouraged to observe, record and analyze what they saw, there was no mention of religious explanations (Nehm & Reilly (2007), Stears (2012) and Vieira & Falcão (2013)). This observation led to the question: to what extent students would be committed to religious beliefs to explain the natural phenomena? By two issues, we investigated the social representations of two groups of students in relation to two phenomena: one that clearly included the life (usual as an object of religious proselytism), and another one that did not include any reference usually mentioned by religious texts, like Earth would be about 4 billion years ago. The questions were: "How do you think the first living being appeared on planet Earth?" And "How do you think Earth was 4 billion years ago?"

Two groups of students surveyed were enrolled at the end of the first cycle (ninth year of elementary school) and second cycle (third year of high school) of Basic Education. These students belonged to a public school in the Rio de Janeiro state, Brazil, with absence of infrastructure (laboratories, educational teaching resources and teachers) and located in a social context where there were churches, especially evangelical, with a strong social and doctrinal action.

METHOD

Social representations are knowledge built and shared in a community, that is, opinions, positions, views and beliefs of a particular group on a particular topic (Moscovici, 2003). For the social representations analysis, we used the Collective Subject Discourse (CSD) proposed by Lefèvre & Lefèvre (2003). The CSD technique aims to summarize the testimony, revealing the social representations of the subjects of the group. In the first step, the key expressions are identified (KE) of each statement. In the second step, similar KE are grouped around the central idea (CI) that unifies. From this, the KE are articulated as a speech-synthesis and CI names this speech. There may be different KE similar groups, so the construction of more than a speech-synthesis is possible and the same subject can participate in more than a speech. The set of synthetic discourses expressed the social representation of the group investigated.

RESULTS

The religious profile (Table 1) and the collective discourse were exposed in the tables bellow. On the question "How do you think the first living being appeared on planet Earth?" (Table 2), there were found the following Central-Ideas: **CSD1-Creationism**; **CSD2- Evolutionism**; **CSD3- Compatibility** and **CSD4- Doubt**. In relation to the question "How do you think Earth was 4 billion years ago?" (Table 3), it there were found the following Central-Ideas: **CSD1- Technology and Society**; **CSD2- Doubt**; **CSD3- Evolutionism** and **CSD4- Creationism**. We surveyed 44 students in ninth year of elementary school and 40 students in third year of high school. At the moment of the research, the both students class had studied evolution relative topics as well diversity of living beings (in ninth year of elementary school) and evolution of species (in third year of high school).

Table 1. Religious profile of the students.

Grade	N	Do not believe in God	Believe in God without religion	Evangelical	Catholic
Ninth year of elementary school	44	1(2%)	18 (41%)	16 (36%)	9 (20%)
Third year of high school	40	4 (10%)	9 (22%)	16(40%)	11 (27%)
Total	84	5	27	32	20

Table 2. How do you think that the first living being appeared on planet Earth?

	Elementary school	High school
Central- Idea	**Ninth year**	**Third year**
CSD1- Creationism	"What I know is that God created. It was through the hands of God, who created the world and all living beings. (...) I just have faith in God and believe that he created everything. God created Adam and then Eve. I do not think, I'm sure it	"I do not think it was through Big Bang or monkeys, but of someone who created every detail. It came from an unbelievable manner, using the (...) words spoken by God. All creation and inspiration of God. God created all things. Through the dust,

	was God who created the first living being". **N= 17 (51%)**	animals and plants were the first to exist on earth. It was through the mud. Also, the way that came to us was the story of Adam and Eve how the first humans who over there". **N=15 (43%)**
CSD2- Evolutionism	"I think there were animals. First the monkey, after all living beings. By bacteria. From a cell over the years on Earth. I think it came from the phenomena of nature. The first living being was when the planet Earth began to cool and emerge of oxygen, then came the species such as plants, animals, humans, etc". **N=8 (24%)**	"Chance, between substances and molecules. I believe that it was a lengthy process in harmonious union of elements of nature. I believe that came about through the Big Bang theory. With the chemical reactions generated by the effects of climate and comets. Organic matter and meteors coming and fused with substances of our planet. It was rich in asteroids and comets that roamed the planet immediately after cooling the Earth. Through microscopic beings, tiny as viruses and bacteria, over time, have been evolving and improving until they become larger species (...). Arose from those factors necessary for the existence of life as water and sunlight to give bacteria that multiplied making more complex beings. For some genetic thing I can not explain. Through the monkey. Maybe the dinosaurs. The first human being alive came about through experience". **N=17 (48%)**
CSD3- Compatibility	"I believe that the first living being was the monkey and then Adam". **N=2 (6%)**	"God. He created everything from the Big Bang. God made a lightning strike which had certain elements put by God to generate the first life". **N=1 (3%)**
CSD 4- Doubt	"I do not know. This type of question, I am not sure at all". **N=6 (18%)**	"I do not know". **N= 2 (6%)**

Table 3. How do you think that Earth was for 4 billion years ago?

	Elementary school	**High school**
Central-Idea	**Ninth year**	**Third year**
CSD1- Technology and Society	"I think we did not have any kind of education, school, and health. People who caught plant and made his own medicine, etc. There was no kind of technology. I think the earth was dominated by people from the medieval century and by those who	"Unlike today because there was no technology that exists today. (...) Old, dry, different clothes. Time, different hair, different ways of being. There was not anything neither than today's technology. It was quite different.

	wrote the bible. I think there were romans among others. (...) And for me, also, a thousand times better that the animals led the planet and not the man. I think it was lagging behind today as technology, electricity, homes, work, etc. Years of horrible caves, without light, without anything to have fun without technology". **N=10 (32%)**	Everything from the humans to the animals. I believe that the way of life of human and species were unique to the present day, without form and void". **N= 4 (15%)**
CSD 2-Doubt	"I do not know, I have no idea, I do not think about it. (...) I have no idea what it was like we were all up as we are, but well evolved". **N=7 (22%)**	"I do not know. I have no idea". **N= 4 (15%)**
CSD3-Evolutionism	"For me, I think there were only animals that were quite different, rocks, few species of life and water, there were no humans. I think it was a very hot place with many volcanoes. An empty place with many species of plants, forest, a forest with no life. (...) There were rivers, oceans. But it did not have much water and the other half was just some land. With dinosaurs and active volcanoes and therefore it did not have much life and vegetation. I think there was some land, Walloon, etc. and more animals than today". **N= 14 (45%)**	"I think the species were still being formed. The very earth's crust would otherwise be a single continent, Pangea. In fact, there are many other animals. (...) There were species that today there are more like dinosaurs. In my theory, the dinosaurs had dominated most of the Earth with little space for mammals. I think it was the dinosaurs, where humans could not live. Over the years and time, Earth was developing gradually these species were extinct. Full tree, a more natural environment. An empty planet, with just bizarre beings. Period Pre - carbon, uninhabitable for some forms of life due ace substances that were in the water and soil. Deserted, only with animals, water, etc. Rich in oxygen, water, animals and plenty of deserts and forest. Based on what I've read, I think the Earth was covered by a dark smoke (CO_2) with huge trees and giant animals. It was a grotesque planet where there was little diversity, few living beings. Uninhabitable atmosphere where there was the heated water and stains on Earth". **N=17 (65%)**
CSD4-Creationism	Unexpressed speech	"The earth was without form and void and darkness was upon the face of the deep, but the spirit of God moved upon the face of the

	waters (Genesis 1: 2)". **N= 1 (4%)**

DISCUSSION AND CONCLUSIONS

How do you think that the first living being appeared on planet Earth? The *CSD 1-Creationism*, greater adherence, is characterized by quotations from Christian scriptures associated with the origin of life. Example: "God created Adam and then Eve". The *CSD 2-Evolutionism* is characterized by the quote of terms associated with scientific explanations for the origin of life and evolution of living beings. Example: "From a cell". The *CSD3-Compatibility* is characterized by the attempt of the students to articulate the idea of divine creation with the scientific explanations. Example: "God. He created everything from the Big Bang". Note that there was more use of terms and scientific explanations among high school students. The *CSD 1- Creationism* in high school group, students reported scientific terms to reject the evolution. Example: "I do not think it was through Big Bang or monkeys". Among this group, the *CSD2- Evolutionism* had better adherence (48%). On Primary Schools, this speech had adherence of 24%.

How do you think Earth was 4 billion years ago? The *CSD3-Evolutionism*, greater adhesion, is characterized by the citation of terms associated with scientific explanations. Example: "active volcanoes". The *CSD 4- Creationism*, lower adhesion, is characterized by quotations from Christian scriptures. Example: "(...) the spirit of God moved upon the face of the waters". The *CSD1-Technology and society* is characterized by the importance given to the absence of technological artifacts and lifestyles of today's society. Example: "Electricity, homes, work, etc". The *CSD1-Technology and society* reflects the reality of young students of both groups heavily involved with the technologies of modern life, such as mobile phones, tablets, TV and intensely stimulated by information, images and different forms of entertainment.

The results analysis indicates that when asked about the origin of the first living being, students remembered most religious explanations. Example: "God, who created the world and all living beings". These explanations were presented constantly by pastors and priests and also by family via biblical texts (Genesis).

When asked about the conditions of the planet Earth in 4 billion years ago, that is, a world "without life", students hardly expressed religious explanations. Students remembered more scientific explanations and lack of technological artifacts that are present in today's world. Examples: "many volcanoes" (*CSD3-Evolutionism*); "(...) with nothing to play without technology" (*CSD1-Technology and Society*). The creationism (CSD 4) was very low membership, just a high school student joined and made the use of biblical quotation "(...) the spirit of God moved upon the face of the waters (Genesis 1: 2)."

The results suggest that in the absence of related terms used in religious proselytism to exemplify natural phenomena (eg, creation of life, living beings, man and woman), that would have been objects of divine action, religious explanation are not expressed. In the case of the planet Earth in 4 billion years ago, religious beliefs were hardly remembered or applied for the construction of speeches, suggesting that religious influence among students has limits.

Usually, in the classroom, the evolution and origin of life are shown speculatively. In this context, science does not stand out or is not expressed and religion is easily remembered. The present results allow us to highlight the importance of the school environment that effectively includes spaces close to the scientific activities of contexts and to promote among students, the practice of science. This research reinforces other studies, which suggests that when students learn through the exercise of procedures such as observation, registration and analysis of phenomena, religious explanations are less expressed.

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REFERENCES

Costa, L., Melo, P., & Teixeira, F. (2011). Reflections on the different views of high school students about the origin of biological diversity. *Science & Education*, v. 17, no. 1, p. 115-128.

Lefèvre, F & Lefèvre, A. (2003). Basic principles and concepts of the collective subject discourse. In: Lefèvre, F. & Lefèvre A, M,C. (eds.). *The Collective Subject Discourse: a new focus on qualitative research (developments).* Caxias do Sul: EDUSC.

Moscovici, S. (2003). *Social representations - Research in Social Psychology.* Petropolis: publisher: Voices.

Nehm, R & Reilly,L. (2007). Biology Majors' knowledge and misconceptions of natural selection. *Bioscence. Science in Context*. *Web.* V.57 No. 3 (263-272).

Rice, D & Kaya,S. (2012). Exploring Relations Among Preservice Elementary Teachers' Ideas About Evolution, Understanding of Relevant Concepts Science, and Science College Coursework. *Sci Educ Res* 42: 165-179.

Stears, M. (2012). Exploring biology education students' responses to the course in evolution at a South African university: Implications for Their roles the future teachers. *Journal of Biological Education*, 46: 1, 12-19.

Vieira,V .(2013). An experience in the field of teaching the theory of evolution in an Adventist denominational school. *Dissertation (Master of Education in Science and Health). Rio de Janeiro: Federal University of Rio de Janeiro, Educational Technology Center for Health* 124 fs.

Vieira, V & Falcão, E. (2014). Teaching the Origin of the Human Being: scientific or religious understanding. Oral presentation at the event *GT River History of Religions and Religiosity of ANPUH*, held at the State University of Rio de Janeiro from 25 to 27 November 2014.

USING PHYSICS LECTURES TO CHANGE STUDENTS' BELIEF AND CONCEPTS ABOUT SAFE BEHAVIOR IN TRAFFIC SITUATIONS

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*Abstract***:** In the context of a road accident prevention program for students aged 16-18, conducted by the state police of North Rhine-Westphalia in Germany, a physics lecture was developed to change students' beliefs about road safety. The lecture consisted of different work assignments (computer simulation as well as pencil and paper worksheets) for small groups of students, all about various physical aspects of road traffic. This lecture was evaluated in a Pre-Post-Design, just before the prevention program, two weeks later and three months later. The results showed that a significant change in students' beliefs in a desired direction occurred.

*Keywords***:** Physics education, road safety, accident prevention, authentic context, authentic assessment

INTRODUCTION

An important part of the german curriculum is for students to acquire several competencies (MSW, 2013). The areas are content knowledge, nature of science, communication and evaluation. In the area of communication competencies, this includes discussions in the classroom, interacting with data and the presentation of ideas. Evaluation competencies are judgement capability with regard to social demands, rational decision-making and to find their own opinion and defend it.

Also, to further emphasize the real-world meaning of the subject of physics, an authentic context is seen as very desirable, this is also true internationally (Chang & Chiu, 2005; Duit & Wodzinski, 2010; Kortland, 2007). Chang and Chiu state that authentic assessments can work *"to cultivate students' abilities such that they can apply them to the real world beyond school" (p. 119, Chang & Chiu, 2005).*

One of the many possibilities of using scientific knowledge to evaluate real-world problems is to evaluate driving habits and road safety from a scientific point-of-view: For example, the energy of a moving car or the shortest possible stopping distance can be calculated (Bresges, 2007; Bresges, 2011a; Busse, 2006; Duit, Häußler & Prenzel, 2002; Westphal, 1995). Physics of road traffic is also used as an example by the ministry of the education: In the area of communication competencies "analysis of traffic situations" and "discussing of behavior in road traffic" are given as examples, in the area of evaluation competencies "judging behavior in road traffic" or "changing own opinion about behavior in road traffic" are used as examples (MSW, 2013).

In the context of traffic accident prevention and interested in changing common beliefs about road safety, a stage show for high schools was established by the ministry of the interior of the state of Northrhine-Westphalia, as described by Weber and Bresges (2012). Earlier evaluations by Hackenfort (2013) and Bresges (2011b) (also described by Hackenfort, Bresges, Weber & Hofmann, 2015) showed that an educational follow-up to this stage show would be beneficial. Hackenfort used a three-part questionnaire to evaluate the impact of the stage show and found it lacking in a few instances, especially areas of subject knowledge. Bresges evaluated the process of the implementation of this stage show and reported a high number high school teachers who wanted to have am more thorough follow-up to the stage show.

A physics lecture (as one of four different lectures) was designed to use the messages of the stage show (drive safely, don't drink and drive, etc.) as an authentic context. The goal was to use this context to see if the students change their beliefs and reevaluate their own driving habits. The design of this lecture and the accompanying evaluation will be covered below. Other lectures were designed for various teacher, as previously described by Weber & Bresges (2012, 2014).

DESIGN OF LECTURE

The lecture was designed to give the students the opportunity to evaluate driving habits with their scientific knowledge. For this reason, the lecture consisted of two parts: First, learning about the physics of road traffic, and second, evaluation of a real traffic accident report (provided by the police). The work sheets were developed after informal discussions with high school teachers and discussions with other experts in the field of physics didactics. The contents were chosen to correspond with the curricula of the state of North Rhine-Westphalia (MSW, 2013).

The students were first divided in small groups. Then every group was assigned three worksheets in a random order. Each worksheet aimed to introduce one aspect of the physics of road traffic:

The first worksheet was called “Forces in Road Traffic”. The students had to calculate the acceleration of a suddenly stopping car (as in a car crash) and deduce from that the force, which a body would experience and find an equivalent mass in normal earth gravitation (e.g. “laying 300 kg of stones on a human body”). After that they had to calculate the force of various cars (all depicted on cards, see figure 1) and their energy after accelerating a certain distance.

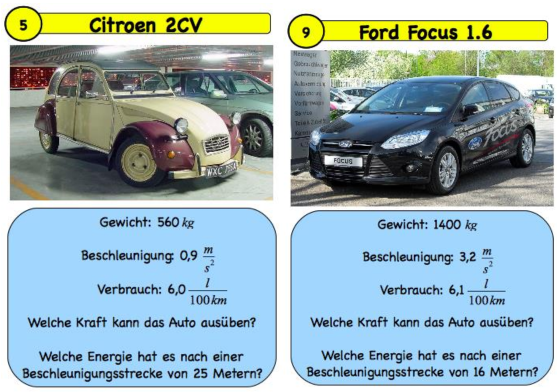

Figure 1. Example of cards (in german)

The second worksheet was called “Thinking distance, braking distance and stopping distance – velocities in road traffic”. The students had various problems to solve, they calculated thinking distances for concentrated and distracted drivers as well as the stopping distance for an intoxicated driver. The last problem was to calculate braking time and distance from a known deceleration rate and velocity.

The third worksheet was called “Stopping distance and collision speed”. The students used a computer simulation called “Mechanik und Verkehr” (example screenshot in figure 2) to test their own assumptions about collision speeds (“If I am 20 km/h faster and normally would have stopped just before an object, which collision speed do I have?”). Also they test different cars to see how small the impact of better brakes or faster reaction time can be if the velocity exceeds the safe amount.

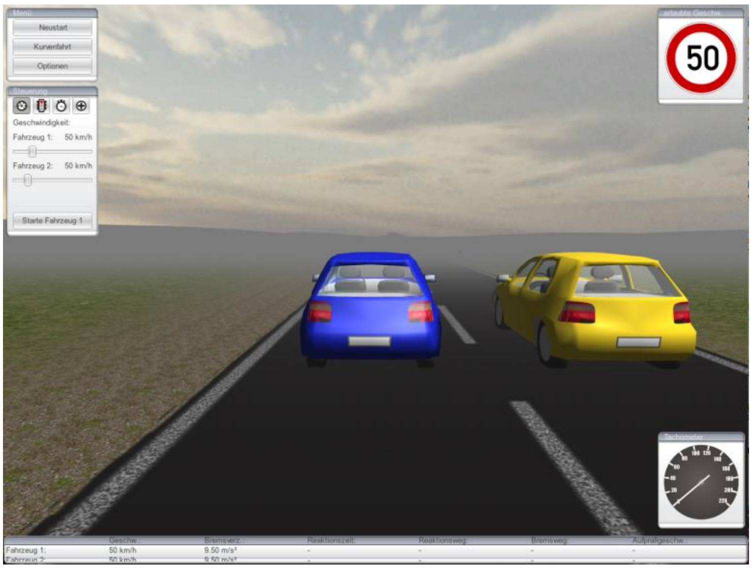

Figure 2. Computer Simulation “Mechanik und Verkehr”

After the three worksheets a traffic accident report is given out to all groups. The students have to analyze the described accident and find the reasons for this accident. To do that they have to use the knowledge they got from the physics worksheet. They also have to draft various ideas to prevent the accident, for all in the accident involved parties. After that a discussion with all students is conducted where the students present their analysis of the accident and should come to a verdict, which of the involved parties is responsible for the accident. This verdict has to be based on a scientifically grounded argument.

EVALUATION

Test design and data analysis

The lecture was implemented in four schools. In every school the stage show of the Crash Kurs was performed right before the lecture. To evaluate the impact of the lecture, a questionnaire was given out to the students right before the stage show, two weeks after the lecture was conducted and three months later.

The questionnaire consisted of four parts:

- 9 Sociodemographic questions (e.g. age, gender)
- 12 Questions about emotional, cognitive and behavioural attitudes (marked with „E“)

- 32 Questions about threat assessment (marked with „G“)
- 14 Questions about the physics of road traffic (marked with „W“)

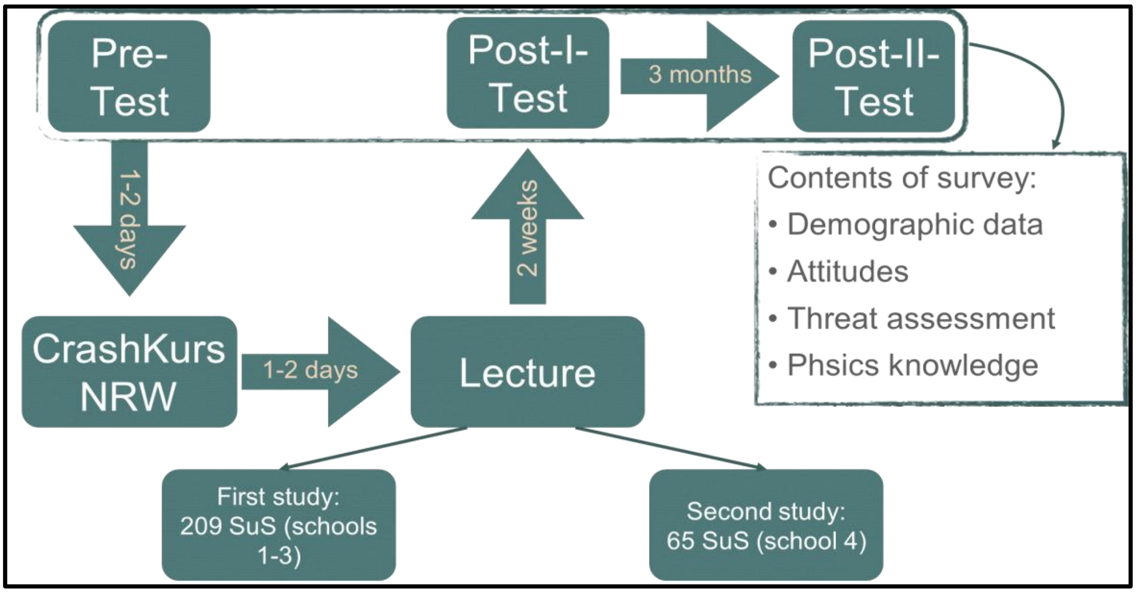

Figure 3. Study design

The questionnaire was modeled after the aforementioned impact evaluation of the stage show (without educational follow-up). By comparing the results of this previous impact evaluation and the described study it should be possible to see if there is an impact of the educational follow-up, i.e. changing the beliefs of the students more deeply. For that reason, the all items used in this study were also used in the impact evaluation (Hackenfort, 2013).

Most of the questions were answerable with a rating scale, with different scales:

- The rating scale for the attitude questions were drawn from a previous study (Holte, 1996) and used a 4-point scale.
- The rating scale for the threat assessment questions were modeled after Hackenfort (2007) and used a 6-point scale.
- The physics questions were drawn from Busse (2006) and used a multiple choice test

Hackenfort (2013) used a pause of three months between Pre- and Post-II-Test, reasoning that this is long enough to see a lasting effect. To better compare the two studies, this time period was used again.

After the first survey with three schools (209 students), the findings suggested that the students drew appropriate conclusions from the accident prevention point of view. In the field of the physics of road traffic the improvement in subject knowledge was negligible. So for a second survey, improvements were made in the worksheets. This was done in accordance with the ideas of Design-based Research (2003). The improvements were minor, e.g. connected values were identically colored and more appropriate values were chosen for a few of the assignments. Also, some explanations were slightly extended.

The subjects of both surveys were chosen randomly from all available schools in the state. Within participating schools, all students who attended the Crash Kurs NRW were subjected to both lecture and questionnaires.

The study followed a "within-subjects"-design, so only the answers of students who participated in all three questionnaires were analyzed. To minimize the risk of false positives in the ANOVA (see Sedlmeier & Renkewitz, 2013) the effect size was calculated first. For an effect size (Cohen's d, Cohen, 1992) smaller than 0.2, no test of significance was performed. The results of the ANOVA were only deemed significant if p is smaller than 0.05. A post-hoc-analysis also determined that all significant differences had a power greater than 0.8.

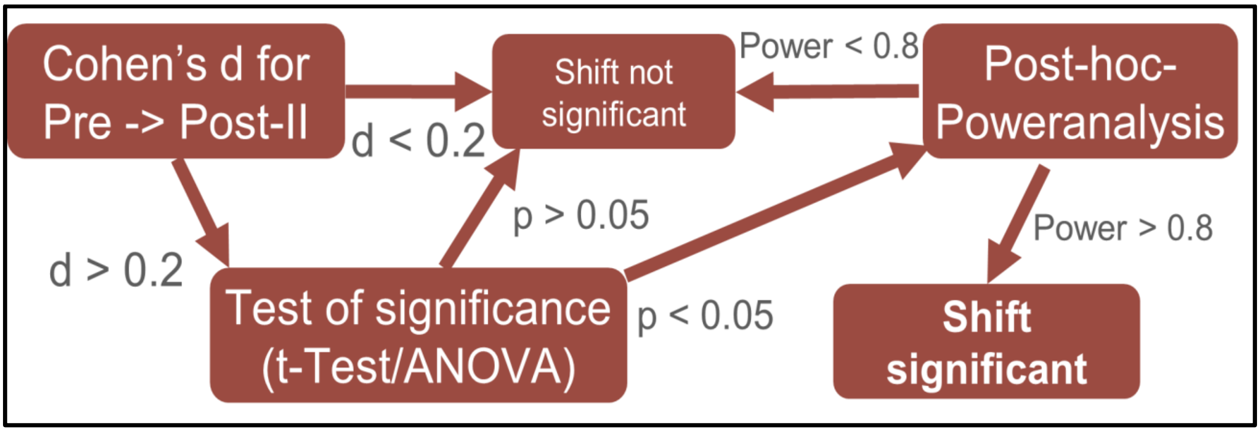

Figure 4. Evaluation design

One problem was, that quite a few students participated only at one or two dates, not on all of them. Normally, this missing data would prompt a case-deletion. According to Sedlmeier & Renkewitz (2013), this is a suboptimal strategy, especially for data not missing completely random. The Little-Test (Little, 1988) was used to determine this. The results of the Little-Test suggested that the missing cases should be simulated with an imputation method. The EM-Algorithm was chosen as this imputation method; it generates the missing values by creating mathematical models for the whole data set. A more in-depth explanation for this algorithm is detailed by Dempster, Laird and Rubin (1977). For even better comparison, the data was analyzed both with and without the simulated cases. As noted by Weber (2015), the difference is not that big, it mostly underlines the following results. For that reason, this second evaluation is omitted here.

Test results

For all 68 questions, results were calculated, using the aforementioned methods. The following examples should give an insight in the current findings. For all questions only the difference in the long-term survey (from Pre- to Post-II-Test) were interesting, the short-term effect was always bigger, for the study, long-lasting effects were deemed more important to estimate the long-term change in students' belief.

In Figure 5, the accident probability (as estimated by the students) for drivers in general is shown, in this case from the first survey ("1" was a low accident probability, "6" a high one). The students were asked to assess this probability for various traffic situations (G1-G8) as part of the questions about threat assessment (see above). The figure shows, that after the educational follow up a significantly higher estimate of accident probability (significance marked by *) for the situation G5, “driving like you always do”, with a Cohen's d of 0.3 (found in parentheses) can be found.

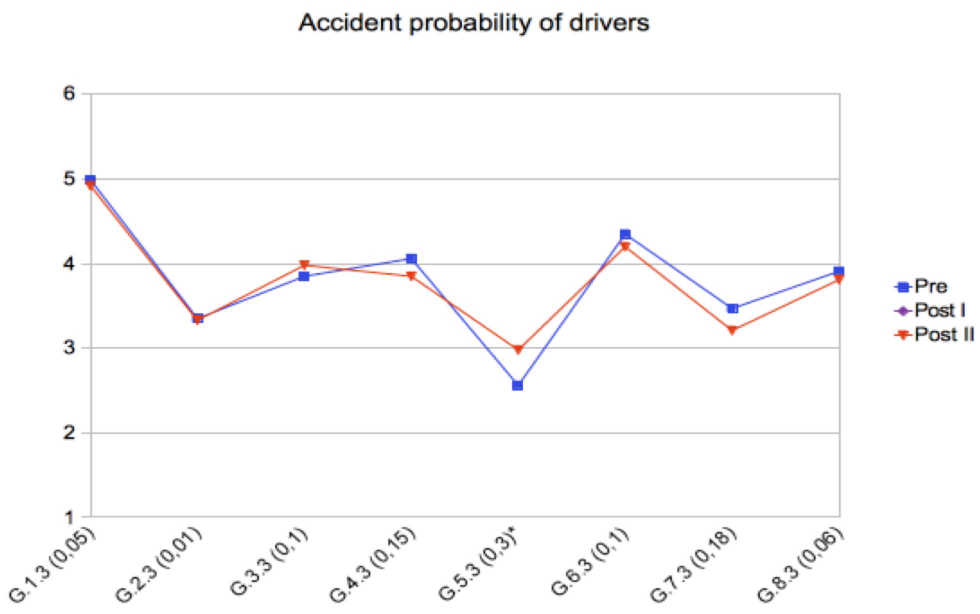

Figure 5. Estimated accident probability

In Figure 6, two significant changes in the student’s estimation about their personal ability (again, “1” means low ability and “6” means a high one) to prevent an accident can be found. The first one is in the situation G3 (“under the influence of a little amount of alcohol”), with a Cohen's d of 0.39 and the second one in situation G6 (“at night on a trunk road with a speed of 140 km/h”), with a Cohen's d of 0.27.

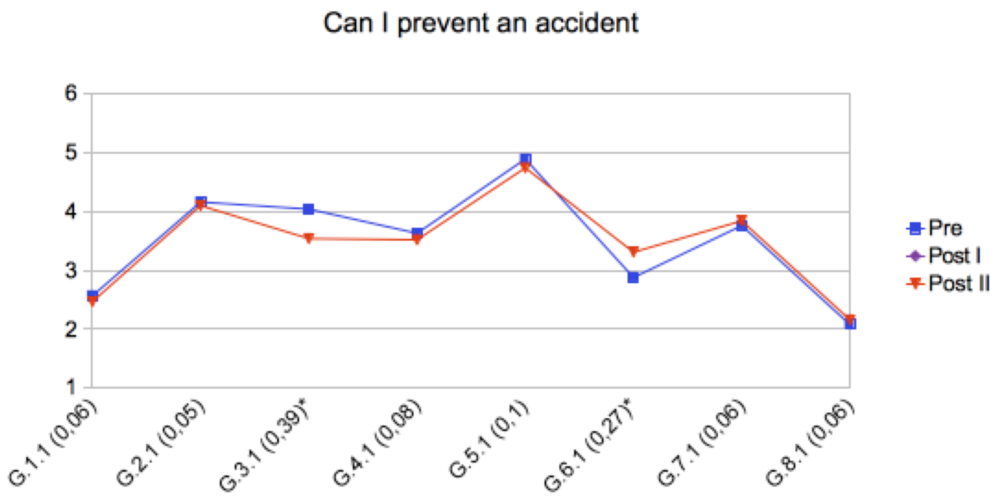

Figure 6. Estimated ability to prevent an accident

In Figure 7, answers to questions about subject knowledge (marked with "W") from the second survey are shown. To answer the questions W2.1 and W2.2 correctly, the students had to understand that doubling the velocity of a car means quadrupling the braking distance. The students give significantly higher answers, with a Cohen's d of 0.45, resp. 0.28.

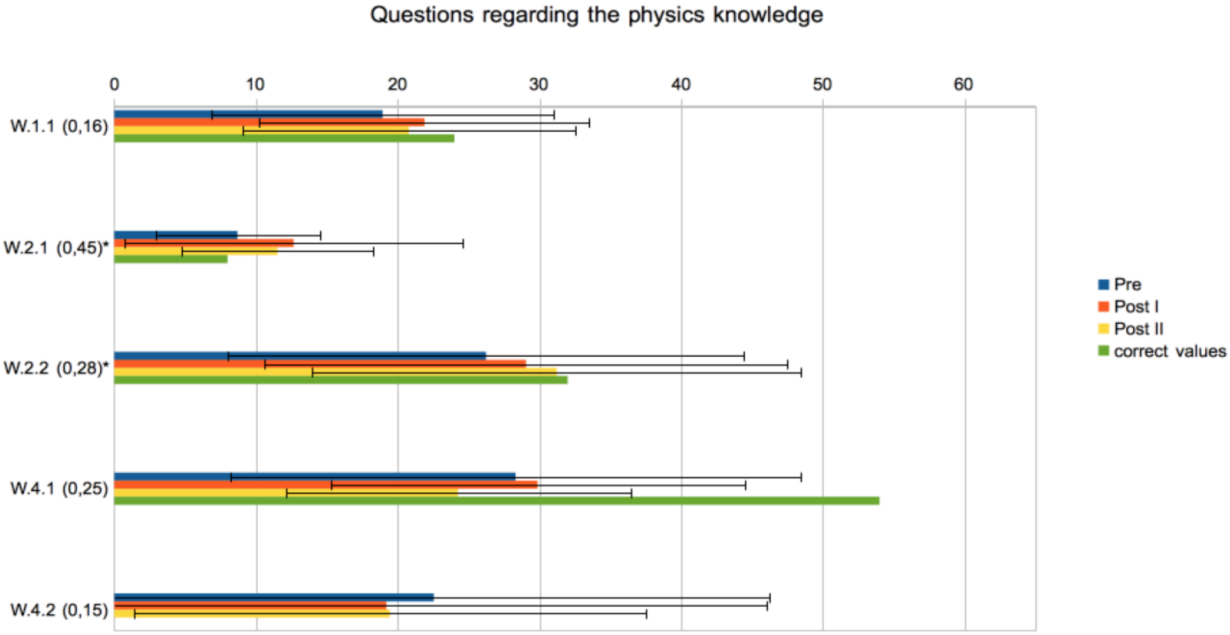

Figure 7. Various questions about physics

Almost every significant change was a change in the intended direction (except G.6.1 in Figure 6), the students reevaluate their personal beliefs about road safety and change them, they also change their understand of road physics. In the following table, which depicts every significant change in both surveys, such (beneficial) changes are marked green and changes which were significant, but in an unintended direction, were marked red (the questions are marked with "E", "G" and "W", see above).

Question	Schools 1-3	School 4		Question	Schools 1-3	School 4
E2	**0,19**	0,33		G_6_1	**0,27**	0,21
E4	**0,20**	0,20		G_6_3	0,10	**0,48**
E7	0,04	**0,39**		G_7_2	0,02	**0,32**
E9	**0,23**	0,06		G_8_4	**0,21**	0,26
G_2_3	0,01	**0,40**		W_2_1	**0,19**	**0,45**
G_2_4	**0,27**	0,22		W_2_2	0,07	**0,28**
G_3_1	**0,39**	0,05		W_4_2	**0,20**	0,15
G_5_3	**0,30**	0,31		W_5_c	**0,19**	**0,56**
G_5_4	0,13	**0,44**				

Table 1. Table of all significant changes

As can be seen in table 1, there are a lot of "green" changes in the first survey. This is, from an accident prevention point of view, a good thing. The changes in the answers to physics subject questions (marked “W”) are very small or even negative. That prompted the afore mentioned change in the worksheets (see above). As can be seen in the table, the changes in the physics questions are much stronger and significant. At the same time, a lot of the other changes either have a smaller effect size or even point in an unintended direction.

To understand this and before a comparison to the results of Hackenfort (2013) could be drawn the sociodemgraphic data was examined further. This revealed a difference in age distribution and driving experience between the two surveys.

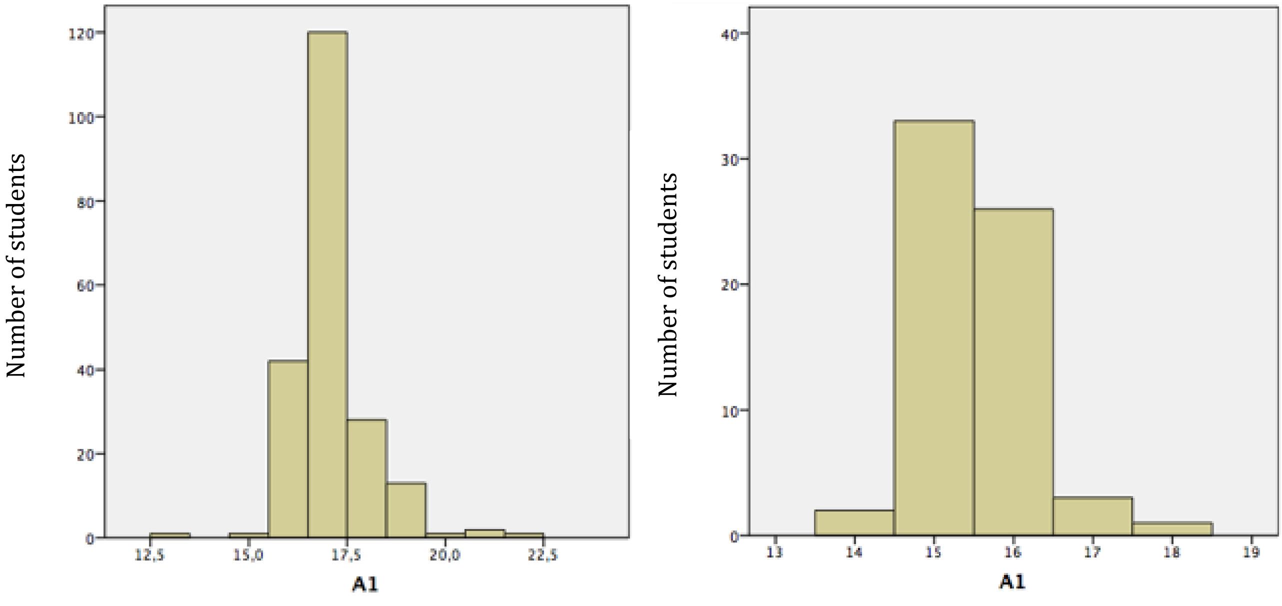

Figure 8. Age distribution in first (left side) and second (right side) survey

Table 2. Driving experience

Driving experience (first survey)	#	Relative number
No drivers license	63	30.1 %
Getting formal drivers education	63	30.1 %
Obtained in 2012	7	3.3 %
Obtained in 2013	31	14.8 %
Obtained in 2014	45	21.5 %

Driving experience (second survey)	#	Relative number
No drivers license	59	90.8 %
Getting formal drivers education	6	9.2 %

As can be seen in Figure 8 and Table 2, the students in the first survey were on average 1-2 years older and 70% either had a driver’s license or were in the process of getting one.

CONCLUSION

Firstly, a comparison with the results of Hackenfort (2013) (also presented in Hackenfort et al., 2015), shows that the changes in the first survey are more pronounced. Considering that the state police uses the same stage show this leads to the conclusion that the educational follow-up has a stronger impact than the stage show alone.

This is an important conclusion as it leads to a broader application of physics lessons outside of schools, which is what the core curricula of the ministry of education (MSW, 2013) tries to promote. Also the questions about attitudes and threat assessment were selected to give an insight in a possible improvement of competencies in the areas of communication and evaluation (Weber, 2015). The positive change in the students' answers suggests that this lecture is not something extracurricular, but that it fits in the normal school curriculum.

Secondly, the second survey demonstrates that this impact can be a lot less pronounced in certain situations. In this case, the students received an improved version of the worksheet (which shows in their answers to the physics subject questions) but especially in the area of threat assessment the students seem to change in an unintended way. This could stem from either a change in the stage show or the worksheet. The stage show has a remarkably stable impact (Hackenfort, 2013) and all changes in the worksheet were not in an area which could yield such a change. This leads to the conclusion that the students in the second study were a little bit too young and unexperienced. As the afore mentioned authors (Bresges, 2007; Bresges, 2011a; Busse, 2006; Duit, Häußler & Prenzel, 2002; Westphal, 1995), who all promoted road traffic as an authentic context, made no mention about the age of students, this is a concern. Authentic context is an important part of modern physics education, so every authentic context should be chosen carefully. For that reason, it seems only prudent to thoroughly investigate this particular context for its feasibility in school lessons.

Further research should also focus on the ability of this physics lesson to change student's abilities to think about road safety without the context of the police stage show. Also, it would be interesting if the last part of the lesson were a news report and not a police report. Especially as news reports are often written in a more unclear way than police reports. Equally interesting would be to see if physics lessons like this are only important for german high schools or if there is an opportunity to implement this in more european countries.

REFERENCES

Bresges, A. (2007). *Untersuchung und Veränderung des Verhaltens von Verkehrsteilnehmern aus der Perspektive der Didaktik der Physik.* Habilitiation thesis: University Duisburg-Essen. Duisburg, Germany.

Bresges, A. (2011a). *Unterrichtliche Nachbereitung des Unfallpräventionsprogrammes „Crash Kurs NRW" - eine physikbezogene Aufgabe mit fächerverbindendem Anspruch*. Phy-Did B - Didaktik der Physik (ISSN 2191-379X), Jahrgang 2011.

Bresges, A. (2011b). P*rozessevaluation des CrashKurs NRW. Bericht der wissenschaftlichen Begleitung.* Düsseldorf: Ministry oft the interior North Rhine-Westphalia.

Busse, A. (2006). *Computersimulationen zu Mechanik und Straßenverkehr in der gymnasialen Oberstufe.* PhD thesis: University Duisburg-Essen. Mülheim an der Ruhr, Germany.

Chang, S., Chiu, M. (2005). The Development of Authentic Assessments to Investigate Ninth Graders' Scientific Literacy: In the Case of Scientific Cognition Concerning the Concepts of Chemistry and Physics. In: *International Journal of Science and Mathematics Education*, 3/1, S. 117-140. DOI: 10.1007/s10763-004-5239-0

Cohen, J. (1992). A power primer. *Psychological Bulletin*, 112 (1), S. 155-159.

Dempster, A.P., Laird, N.M., Rubin, D. B. (1977). Maximum Likelihood from Incomplete Data via the EM Algorithm. In: *Journal of the Royal Statistical Society. Series B (Methodological)*, 39 (1), S. 1-38

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32(1), S. 5-8. DOI:10.3102/0013189X03200100133

Duit, R., Häußler, P., Prenzel, M. (2002). Schulleistungen im Bereich der naturwissenschaftlichen Bildung. In: Weinert, F.E. (Hrsg.), *Leistungsmessungen in Schulen, 2. Auflage*, S. 17-32. Weinheim und Basel: Beltz Verlag.

Duit, R., Wodzinski, C.T. (2010). Merkmale guten Physikunterrichts. In: Duit, R. (Hrsg.). *Piko-Briefe. Der fachdidaktische Forschungsstand kurzgefasst.* IPN Kiel. Retrieved from: http://www.ipn.uni-kiel.de/de/das-ipn/abteilungen/didaktik-der-physik/piko/pikobriefe032010.Pdf

Hackenfort, M. (2007). *Entwicklung und Evaluation eines zielgruppenspezifischen Präventionsprogramms zur Verringerung von Wegeunfällen.* PhD thesis: University Duisburg-Essen. Legden, Germany.

Hackenfort, M. (2012). Psychologische Sicherheitsforschung: Ursachen und Folgen von subjektiven Fehleinschätzungen und ihre Bedeutung für den Straßenverkehr. *SIAK Journal: Zeitschriftfür Polizeiwissenschaft und polizeiliche Praxis*, 3, S. 16-26.

Hackenfort, M. (2013). Untersuchung der Wirkungen eines Unfallpräventionsprogramms mit konfrontativen Stilmitteln. In: *Zeitschrift für Verkehrssicherheit*, 59(3). S. 155-160.

Hackenfort, M., Bresges, A., Weber, J., Hofmann, U. (2015). Rezeption und Wirkung der Kampagne CrashKurs NRW. In: Klimmt, C., Maurer, M., Holte, H., Baumann, E. (Hrsg.), *Verkehrssicherheitskommunikation*, S. 175-197. Wiesbaden: Springer Fachmedien. Doi: 10.1007/978-3-658-011307-7_10

Holte, H. (1996). *Kenngrößen subjektiver Sicherheitsbewertung.* Bergisch Gladbach: Berichte der Bundesanstalt für Straßenwesen.

Kortland, J. (2007). Context-based science curricula: Exploring the didactical friction between context and science content, *ESERA*. Malmö, Sweden. Can be retrieved from: http://www.staff.science.uu.nl/~kortl101/art_esera-07-paper.pdf

Little, R. (1988). A Test of Missing Completely at Random for Multivariate Data with Missing Values. *Journal of the American Statistical Association* 83 (404), S. 1198-1202.

Ministerium für Schule und Weiterbildung (MSW) (2013). *Kernlehrplan für die Sekundarstufe II Gymnasium / Gesamtschule in Nordrhein-Westfalen. Physik.* Düsseldorf: Ministerium für Schule und Weiterbildung. Retrieved from: http://www.schulentwicklung.nrw.de/lehrplaene/upload/klp_SII/ph/GOSt_Physik_Endfassung.pdf

Sedlmeier, P. Renkewitz, F. (2013). *Forschungsmethoden und Statistik für Psychologen und Sozialwissenschaftler. 2., aktualisierte und erweiterte Auflage.* Hallbergmoos, Pearson Deutschland GmbH.

Weber, J. (2015). *Konzeption und Evaluation einer Nachbereitung zum Unfallpräventionsprogramm „Crash Kurs NRW“.* PhD thesis: University of Cologne. Cologne, Germany

Weber, J., Bresges, A. (2012). „*Authentic Problems for authentic assessment in Physics Education“.* Proceedings of WCPE 2012.

Weber, J., Bresges, A. (2014). Using serious games and computer simulations in an authentic context for physics education. In: Constantinou C.P., Papadouris, N., Hadjigeorgiou, A. (Hrsg.).*E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning. Part 4 (Olympiou, G., Marzin-Janvier, P.), (104-115).* Nicosia, Cyprus: European Science Education Research Association. ISBN: 978-9963-700-77-6

Westphal, W. (1995). Wieweit eignet sich Physikunterricht zur Verkehrserziehung?. In: *Naturwissenschaften im Unterricht. Physik.* 6 (30). S. 9-11.

PUPILS' CONCEPTIONS OF BIOLOGICAL EVOLUTION THROUGHOUT SECONDARY SCHOOL IN FRANCE

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Abstract: The biological theory of evolution (ToE) is fundamental knowledge for understanding modern biology. That is why it is important that it is taught from an early age to avoid misconceptions. Biological evolution is taught in various school levels worldwide but, it is complex knowledge. This topic, by the nature of its knowledge, is particularly exposed to confrontations with the ideas belonging to the public domain and beliefs influenced by cultural factors. In this communication, we analyse the place of the ToE in the French curriculum and we test the relationship between secondary school pupils and the knowledge "Evolution". In France, the idea of evolution of living species is introduced in the curriculum using the idea of unity and diversity of living things and the phylogenetic classification. It is explicitly approached toward the end of compulsory lower secondary school. A written questionnaire submitted to secondary school pupils (K6 to K9) enables us to study their conceptions about the evolution of the living species. The study shows that secondary school pupils have knowledge about biological evolution but it reveals a mixed conception between "Pro-évolutionnist" and "Trans-mutationist" conceptions. The "trans-mutationist" conceptions are still very present in K9 students to explain the mechanisms of evolution. This conception constitutes a real obstacle to learn the ToE because it totally excludes the idea of randomness. This can be a major obstacle to the acquisition of real evolutionary thought. This research calls to explore the effect of introducing the idea of randomness earlier in school.

Key-words: compulsory school - biological evolution – pupils' conceptions

INTRODUCTION

Teaching the evolution of living species is today at the heart of many studies from primary school to university (Carette et al., 2013; Coquidé & Tirard, 2009; Gobert, 2014). This can be explained by its fundamental importance in modern biology that pushed toward new ways of thinking biology for the last two hundred years, and showed many developments more recently with the development of molecular biology. It is also a controversial topic when it comes to religious beliefs. Many countries face strong anti-evolutionary movements and creationists lobbying (Committee on revising Sciences and Creationism, 2008; Holliman & Allagier, 2006). In some cases, these beliefs even become obstacles to learning this concept (Basel et al., 2014; Foster, 2012; Reiss, 2014). As a consequence, it is also a delicate object of teaching. It is complex and involves another way of thinking science. Moreover, strong beliefs held by students may impede their learning of the evolution of life. The aim of this research is to explore the evolution of students' conceptions throughout lower secondary school in France. It follows a study done in French primary schools (Jégou-Mairone, 2011).

Students' evolution acceptance

The difficulty for students to accept evolutionary ideas has been shown to be either directly linked to the intrinsic conceptual difficulty of the theory of evolution, or linked to non-scientific ideas (Aroua, Coquidé & Abbès, 2013). The first type of difficulties is intrinsic conceptual difficulties of the theory of evolution. It concerns the dynamic of the evolutionary model and the related mechanisms, in particular, natural selection, complicated by its historical nature (van Dijk & Reydon, 2010; Smith, 2010), or the specific enquiry process of historical sciences (Aroua, 2006). The second type is linked to no scientific ideas. In other words, students' beliefs have been shown to be influenced by cultural or sociocultural factors that may not be compatible with evolutionary science (Hanley, Bennett & Ratcliffe, 2014; Yasri & Mancy, 2014).

Conceptions of primary and high school students

The baseline of this research is to consider what students know about evolution at the end of primary school and where secondary school takes them. There are few studies concerning primary school children and their idea about evolution (Jégou-Mairone, 2011; Campos & Sà-Pinto, 2013). Jégou-Mairone (2011) underlines the fact that, despite the difficult nature of the topic, the majority of young children tested in France accept the idea of evolution. Furthermore, they have effective knowledge on some facts of evolution, in particular, concerning emblematic figures such as dinosaurs, mammoths or humans. This idea of evolution is mainly expressed in the form of "creation + evolution". In this case, children build a mixed conception where they consider first a "creation of species" and then an evolution of these species. This idea becomes predominant in schools where religious education at home is also very present. Therefore, the study highlights the strong influence of extra-scholar institutions, in that case, the family, on children's answers. Very often they mention God to justify their choice, although creationist ideas are rarely found. The dominance of a model of the type "creation + evolution" stresses the need for children to develop their own understanding taking the form of a compromise between both institutions around them (family and school).

The studies concerning high school students in France show that students have several conceptions. Fortin (1993) reveals four types of student's conceptions: a 'creationist' conception implying a divine intervention on the species, a 'no-evolutionary' conception which can be approach to the form 'creation+evolution' mentioned above, a 'transmutationist' conception which considers that mutations always have a positive consequence on a species and a 'pro-evolutionary' conception close to the actual theory.

Evolution in French curriculum

It is important to remind that the French context is characterized by a strong dominance of secular values involving the absence of religion in public education. This leads to an orientation of teaching evolution related to its relationship to knowledge and trying to address the misconceptions that might be associated to that knowledge.

The main characteristic of French curriculum about evolution is its entry focusing on the unity and diversity of living species and the classification of living things. In primary school, children approach the idea of species by discovering the diversity of living things and to identify objective criteria to sort them (MEN, 2008). The idea of evolution appears in secondary school in K6 with the use of the phylogenetic classification to highlight the evolutionary history and the relationship between organisms (MEN, 2008). The introduction in K6 is then enriched in K7 through the study of fossils species in order to reinforce the idea of biodiversity and prepare an understanding of the theory of evolution. The teaching of evolution really becomes explicit in K9 at the end of lower secondary school (also the end of common compulsory education in France) with a focus on the understanding of the link between the classification and evolution, the construction of unique tree to represent evolution across the geological times, and the random changes of the mechanisms of evolution.

From this context, we keep the idea that children in primary school have some knowledge about evolution. However, it can be noted firstly that they often have to merge divergent discourses between family institutions and school institutions, and secondly that evolution mechanisms are only lately addressed explicitly throughout compulsory education in France.

In this communication we address the following research question: what are students' changes of conceptions regarding the theory of evolution throughout secondary school in France?

METHOD

This study used a paper-and-pencil questionnaire with 13 questions (multiple choices questions and open questions). Figure 1 presents two examples of questions: an example of multiple choices questions (n°9), and an example of open question (n°12). The questions are derived from a previous work of Jégou-Mairone (2011) focusing in primary school level and therefore the validity of the questionnaire has been tested in that context. The questions test knowledge that can be grouped in 3 categories: (1) effective knowledge related to extinct animals, (2) effective knowledge related to existing animals or humans (such as question 12 presented in Figure1), (3) understanding of evolution mechanisms (such as question 9 presented in Figure1).

Giraffokeryx representation

Photograph of today's giraffe

9. Nowadays, the giraffe is living in the African savanna. Scientists think that this animal, Giraffokeryx, which was living millions of years ago and no longer exists today, is the ancestor of today's giraffe. According to you, how do you think the evolution of Giraffokeryx into the giraffe took place?

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12. With what sentence(s) do you agree? *(Tick the box corresponding to the sentence you agree the most with)*

☐ Humans, monkeys and all living things are the results of a long evolution.

☐ God created humans and animals and no evolution has happened since. All living things today are exactly how they were when they were created.

☐ God created the first humans and animals. Since then, they have undergone transformation; they evolved to become what they are today.

Figure 1: two examples of questions.

It was given to 71 lower secondary school students (K6 to K9) from the same secondary school. The school was selected because teachers were voluntary to participate and it was considered an exemplary case, in the sense that children attending the school have results in national examination that are in the national average. All the children from a same class answered the questionnaire with no specific selection of the children.

Our analyses are based on the conceptions proposed by Fortin (1993). These conceptions allowed us to define four categories of analyses presented in Table 1 with their main characteristics and examples of students' answers. As such, students' answers were considered creationist when a divine origin of species was used to explain the evolution of species, and when they expressed no change in time of any species. A second category, referred to as intelligent design, was identified when children speak about a transformation of species over time, after a creation by god. A third category of trans-mutationist conceptions was identified. It regroups ideas where a common origin of living things is expressed, with ideas of metamorphosis or progress. Such ideas therefore exclude the contribution of any random mutation in the process of evolution. Finally, children's ideas were characterized as pro-evolutionists when they spoke about a common origin of living things, as well as an extinction of species and offered as a cause, random mutations and natural selection.

Table 1. Links between characteristics of conceptions and pupils' wording.

Conception	Characteristics	Examples of students' answers (translated from French)
Creationist	Divine origin of species No relation between living things No change	*God created man separately than animals and no change has occurred since. All living things are today exactly as they were when they were created.* *The first animals were the same as today.*
Intelligent Design	Divine origin of living things and transformation of species over time	*God created the first humans and animals. Since then, they have evolved to become as they are today.*
Trans-Mutationist	Common origin of living things No extinction of species Metamorphosis - Progress Primary role of the environment	*The monkeys developed to become real men.*
Pro-evolutionist	Common origin of living things Extinction of species Cause: random mutation Natural Selection; second role of the environment	*Humans, monkeys and all living things are the result of a long evolution.*

Taking as an example the multiple choices question presented in Figure 1 (question 12), the answers were analyzed in the following way: at the question « with what sentence(s) do you agree?", when children answer, "Humans, monkeys and all living things are the results of a long evolution", we count their answer in the category 'pro-evolutionist'. When they answer, "God created humans and animals and no evolution has happened since. All living things today are exactly how they were when they were created", we count their answer in the category 'creationist'. And when they answer "God created the first humans and animals. Since then, they have undergone transformation; they evolved to become what they are today.", we count their answer in the category 'intelligent design'**.**

RESULTS

First, we counted, for each of the questions, pupils' percentage for every category of conceptions. Table 2 presents the percentage of answers for each category of ideas. We choose to present here only the results for K6 and K9 and not in all levels. This choice was made because it is only for these levels that a significant difference can be observed. A Mann-Whitney's test was used to test the significance using the ade4 package within the R software. The results first highlight that globally; students have mixed conceptions between 'pro-evolutionist' and 'trans-mutationist' with few students showing creationist and intelligent design conceptions. We can therefore consider that a majority of students within the classes tested accept the idea of evolution. There is also a significant difference between K6 students' conceptions and K9 students' conceptions. The 'creationist' conception decreases with students' age, and 'pro-evolutionist' conception increases. Furthermore, K6 students' conceptions, mainly 'trans-mutationist', evolve in K9 toward 'pro-evolutionist' conceptions (Table 2).

Table 2. Percentages of different conceptions among K6 and K9 pupils

	Pro-Evolutionist	Trans-Mutationist	Intelligent design	Creationist
K6	34%*	41%*	5%	21%*
K9	51%*	42%	0%	6%*

* Mann-Whitney's test

Secondly, we distinguished percentages of pupil's conceptions for each of the three categories of questions: (1) effective knowledge related to extinct animals, (2) effective knowledge related to existing animals or humans, (3) understanding of evolution mechanisms. We chose to present these results for each of the conceptions possible. Figure 2 presents the percentage of students' conceptions categorized 'pro-evolutionist' according to the three categories of questions (questions over extinct species, existing species or evolution mechanisms). Figure 3 presents the percentage of students' conceptions categorized 'trans-mutationist'. We chose to present only this conceptions because others conceptions were weakly represented. This detailed analysis of answers shows that the difference in conceptions between K6 and K9 depends on the category of questions. Knowledge about the evolution of extinct species seams stable from primary school (Jégou-Mairone, 2011). In the first diagram of the Figure 2, we can see that the majority of pupils has a 'pro-evolutionist' conception when they speak about extinct species, as for example dinosaur or mammoths. However, the idea of evolution of existing species seems only accepted at the end of lower secondary school. Also, in the second diagram of the Figure 2, we can see that the majority of K9 pupils has a 'pro-evolutionist' conception when they speak about existing species, as for example giraffe, unlike K6 pupils. We also note that at the end of compulsory school in France (K9), a majority of students do not reach the stage pro-evolutionary with regard to the understanding of explanatory mechanisms of evolution (Figure 2) and stay in a 'trans-mutationist' conception (Figure 3).

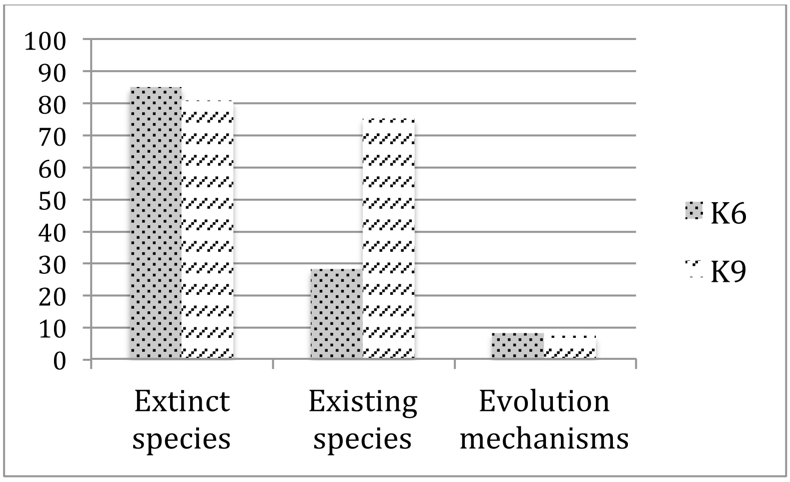

Figure 2: Percentages of 'pro-evolutionist' conceptions depending on the category of questions.

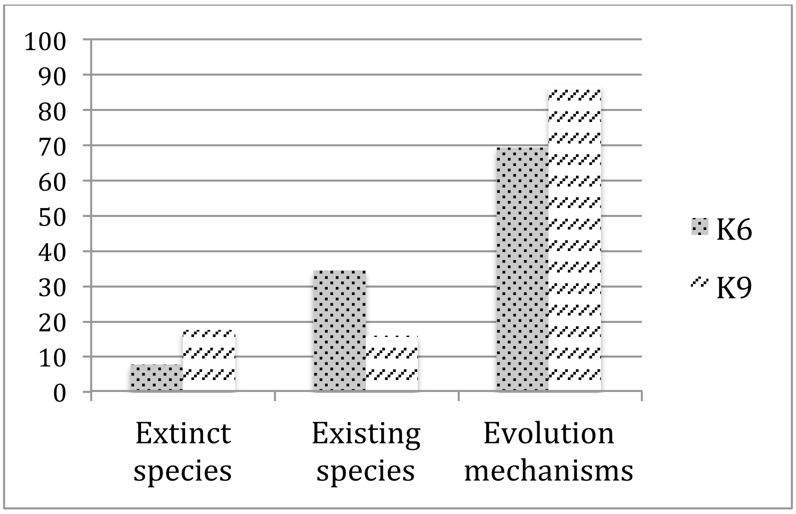

Figure 3: Percentages of 'trans-mutationist' conceptions depending on the category of questions.

DISCUSSION

This preliminary study aims to identify students' conceptions of secondary education (K6 to K9) in order to consider the impact of school curricula during compulsory education.

Jégou-Mairone (2011) showed that students leave primary school with knowledge on some facts of evolution. This study confirms this position by revealing mixed conceptions accepting the idea of evolution with some nuances. It is accepted by K6 pupils especially for extinct species and more difficult in the case of existing species. This difficulty seems overcome at the end of lower secondary school. There is an evolution of students' conceptions mainly in K9. Since K9 correspond to the end of common compulsory education in France, we observed that a majority of students in the sample tested leave compulsory education accepting evolution.

However, despite the teaching of evolution throughout lower secondary school, K9 students still have great difficulties in understanding the explanatory mechanisms of evolution. The majority of students tested has trans-mutationist conceptions, which means that they accept the idea of evolution, but see it as a metamorphoses of species under a stress due to the environment. This result joins the works of Van Dijk & Reydon (2010) and Smith (2010).

This trans-mutationist conception constitutes a real obstacle to learning the theory of evolution. Our study raises questions about the causes of the persistence of this conception. Since Darwin (1859), the theory of evolution evolved towards a synthetic stage. At present, the synthetic theory of evolution leans essentially on the fact that genetic mutations are random. The notion of fate appears then as being a key element of this new theory (Merlin, 2011). Our first interpretation of that result is that students stay in a 'trans-mutationist' position because they might not take into account the contribution of randomness and in particular the contingency to explain the mechanisms of evolution of species. The TM conception totally excludes the idea of randomness and can be a major obstacle to the acquisition of real evolutionary thought. This research opens the way to explore the effect of introducing the idea of randomness earlier in school.

REFERENCES

Aroua, S. (2006). *Dispositif didactique pour l'enseignement de l'évolution du vivant - débat en classe pour l'enseignement de la théorie de l'évolution du vivant en Tunisie.* Thèse de doctorat, ENS Cachan, France et ISFEC de Tunis.

Aroua, S., Coquidé, M. & Abbes, S. (2013). Enseigner l'évolution du vivant dans un contexte concordiste. *Review of science, mathematics & ICT education*, 5-26.

Basel, N., Harms, U., Prechtl, H., Weib, T., & Rothgangel, M. (2014). Students' arguments on the science and religion issue: the example of evolutionary theory and genesis. *Journal of Biological Education, 48*(4), 179-187.

Carette, V., de Biseau, J.C., Wolfs, J.L., Colsoul, A., Leclercq, G., Poncelet J.F., Bohyn, V. Lauriente, B., Serry S. (2013). Analyse des difficultés liées à l'enseignement – apprentissage de la théorie de l'évolution. *Education & Formation*, *298*(3), 87-103

Campos, R., & Sá-Pinto, A. (2013). Early evolution of evolutionary thinking: teaching biological evolution in elementary schools. *Evolution: Education and Outreach*, *6*, 25.

Coquidé, M., & Tirard, S. (2009). *L'évolution du vivant. Un enseignement à risque?*, Paris, Vuibert, adapt-snes.

Committee on Revising Science and Creationism: A View from the National Academy of Sciences, National Academy of Sciences and Institute of Medicine of the National Academies. (2008). Science, Evolution, and Creationism. Retrieved from: http://www.nap.edu/catalog/11876.html

Fortin, C. (1993). *L'évolution: du mot aux concepts.* Thèse de doctorat. Université Paris 7, Paris.

Foster, C. (2012). Creationism as a misconception: socio-cognitive conflict in the teaching of evolution. *International journal of sciences education, 34*(14), 2171-2180.

Gobert, J. (2014). *Processus d'enseignement-apprentissage de raisonnements néodarwiniens en classe de sciences de la Vie et de la Terre.* Thèse de doctorat, Université de Caen Basse-Normandie, Caen.

Jégou-Mairone, C. (2011). Des élèves de 9-12 ans de l'école primaire française et l'évolution des espèces vivantes. *Review Of Science, Mathematics And ICT Education*, 5(1), 81-96.

Hanley, P., Bennet, J. & Ratcliffe, M. (2014). The inter-relationship of science and religion: a typology of engagement. *International Journal of Science Education*, 36:7, 1210-1229.

Holliman, R., & Allagier, J. (2006). The emergence of the controversy around the theory of evolution and creationism in UK newspaper reports. *Curriculum Journal, 17*(3), 263-279.

M.E.N (2008). *Programme de l'école et du collège.* http://eduscol.education.fr/pid23391/programmes-de-l-ecole-et-du-college.html

Merlin, F. (2011). Le « hasard évolutionnaire » de toute mutation génétique, ou la vision consensuelle de la Synthèse Moderne. *Bulletin d'histoire et d'épistémologie des sciences de la vie*, 18(1), 79-108.

Reiss, M.J. (2014) Changing one's mind over evolution. In: *Christians and Evolution: Christian Scholars Change Their Mind*, Berry, R.J. (Ed.), Monarch, Oxford, 318-330.

Smith, M.U. (2010). Current Status of Research in Teaching and Learning Evolution: II. Pedagogical Issues. *Science & Education, 19*(6-8), 523-538.

Van Dijk, E. M., & Reydon, T. A. C. (2010). A conceptual analysis of evolutionary theory for teacher education. *Science & Education, 19*(6–7)

Yasri, P., & Mancy, R. (2014). Understanding Student Approaches to Learning Evolution in the Context of their Perceptions of the Relationship between Science and Religion. *International Journal of Science Education*, 36(1), 24-45.

BIOLOGY RESEARCH PROFESSORS AND REFLECTIONS ON TEACHING PRACTICES OF THE THEORY OF EVOLUTION

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Abstract: The theory of evolution is a unifying and central theory to biology. However, several difficulties are identified by research in science education. In this research, we aimed at exploring aspects of students' conceptual difficulties concerning the theory of evolution from a new perspective: the academy. Thus, we studied aspects related to controversies and consensus on the evolutionary theory among a group of biology research professors of a federal university in Rio de Janeiro so that these aspects could provide elements for understanding the difficulties encountered by students in secondary education. The group of professors are engaged in research and teaching at the undergraduate and graduate levels. The Collective Subject Discourse methodology, which is based on the theory of Social Representations, was used for data analysis. The Social Representation of the group revealed the existence of two distinct scientific discourses on the theory of evolution: Darwinian and neo-Darwinian discourses. Although these discourses reveal the influence of the subjects' research activities, the propagation of these two different views on the theory of evolution (Darwinian and neo-Darwinian) may be associated with difficulties students find in secondary school. The research revealed that in the context of teacher education, the university can be one of the roots of the problems in the teaching of evolutionary theory in secondary schools.

Keywords: theory of evolution, research professors, Social Representations.

INTRODUCTION

The theory of evolution is considered the central theme in modern biology since it gives meaning and articulates different contents and areas of this science. Explanatory contributions from various fields made the evolutionary theory, under neo-Darwinian basis, an empirical fact under any criteria. However, in the educational field its teaching still challenges educators.

Researches in secondary education point to problems of various orders in the teaching of the theory of evolution. Difficulties related to evolutionary concepts; the presence of assumptions, such as religious beliefs that compete with evolutionary explanations; teaching materials, curriculum and flaws in teacher training have been identified as obstacles to seizing the evolutionary content.

One of the most frequent problems identified in the literature is students' difficulties regarding the structuring concepts of the theory of evolution (Richards, 2008). The concept of natural selection, central to evolutionary theory, has revealed difficulties in its understanding, since it requires the articulation of a set of ideas, such as "descent with modification", "differential reproduction" and "variability". Natural selection has also been seen as "abstract" by students who question its "lack of purpose", as well as lack of empirical data (Abrantes & Almeida, 2006; Anderson et al., 2002). "Evolution", "adaptation" and "competition" have also revealed difficulties as they are associated with different meanings. "Evolution" is close to the sense of "purpose" and "improvement" and may even mean "awareness" of the species involved in the evolutionary process. "Adaptation" can be misunderstood as an individual process of an organism and "competition" would be a violent behavior (Tidon & Lewontin, 2004). "Theory" has been understood as something speculative and temporary in a pejorative sense (Branch & Mead, 2008; Cunningham & Wescott, 2009).

Due to this setting, the present research investigated aspects of the theory of evolution that could be seen as especially challenging in the educational context: difficulties related to the structuring concepts of the theory of evolution. Would scientific concepts be in fact very difficult? Or would they be too complex or include specific difficulties, such as scientific controversies, which may hinder understanding for both teachers and secondary school students?

To better understand this issue, we investigated the perceptions of a group of biology research professors regarding the theory of evolution, specially controversies and consensus, that could provide subsidies for a better understanding of secondary students' problems concerning evolutionary theory. These professors constitute a link between the scientific production, undergraduate biology education and teacher training and could contribute to elucidate the difficulties encountered in the teaching of the theory of evolution.

METHOD

For this study, we selected three questions: 1. In your own words, how would you summarize the "basics" of the theory of evolution?; 2- What are the controversies of the theory of evolution and how do you see them?; and 3- What is the consensus regarding the theory of evolution?

Individual interviews were held with 17 research professors of the Genetics and Ecology Departments of a federal university in Rio de Janeiro. All of them have contact with evolutionary assumptions in their research lines and work with both undergraduate and graduate students.

The theory of Social Representations (SR) (Moscovici, 2003) was used as theoretical reference. We chose to work on this theory in order to capture, as much as possible, the diversity of opinions related to the investigated content. One might expect that only the scientific concepts related to the topic permeate the educational activities at different levels of education: basic, undergraduate, graduate and laboratories. However, controversial assessments on specific concepts of the theory of evolution, such as randomness and pace of selective processes of differentiation, are also found in the specialized literature, which may contribute to different personal views of research professors.

We are interested in identifying and characterizing more complete views of contents that are possibly included in these professors' convictions and not only in checking the presence of scientific content. Since these professors may emphasize certain aspects or scientific concepts related to evolutionary theory, this direction is recommended.

The qualitative-quantitative methodology of Collective Subject Discourse (CSD) (Lefèvre & Lefèvre, 2003) was used for data analysis. The CSD allows us to capture the representations of the subjects that embrace and profess belief systems, values and actions in a typical social context. In order to establish the common ground group explanations, we asked professors to speak freely about the "basics" of the theory of evolution, exposing their opinions about its controversies and consensus. The CSD was built from the individual statements. The key expressions of all investigated subjects were grouped according to the common elements that they possessed and formed one or more synthetic discourses. Each CSD is appointed by a central idea. In the CSD, the responses of the subjects are faithfully reproduced and built in the first person singular since they express the collective sharing of the group on a specific topic.

RESULTS

This section presents the collective discourses that were expressed and constructed for the three questions explored in this study. Next to each central idea, which nominates the CSD, we present the number of professors (n) and percentage (%) of adherence to each discourse, serving as an element to support data interpretation. The sum of the percentages obtained from CSD is greater than 100%. This indicates that the CSD are not mutually exclusive because the same interviewee can adhere to more than one central idea. The CSD was edited for a better organization of this paper.

Question1 - In your own words, how would you summarize the "basics" of the theory of evolution?

Figure 1 shows that four discourses were formed.

1. The theory of evolution is presented with epistemological references - references to the origin, structure, status, validity and usefulness of the knowledge produced by evolutionary theory are presented in this discourse.

2. Classic Darwinian Discourse - the theory of evolution is explained from scientific facts that support the central Darwinian mechanism: natural selection.

3. Neoclassic discourse - the theory of evolution is defined based on neo-Darwinism: natural selection, genetic and ecological mechanisms.

4. Discourse of the distinction between 'development' and 'progress' - answers that emphasize the common misconception of evolution meaning progress.

1- The theory of evolution is presented with epistemological references. (n = 9 / 53%)
It is a theory that seeks to explain why what we call biodiversity today, the multiplicity of forms of life, their similarities and differences. The theory of evolution explains how changes occur at all levels (...)The theory is much more than that: I would say that is a theory created in the 19th century that in essence is equal to current theory. It is a guide to interpret all biological data. It is the only theory with great explanatory power originated in biology. (...) Evolution is not a theory, it is the fact that things change. It is a forwarding of ideas.
2- Classic Darwinian Discourse. (n=8 / 47%)
The theory of evolution based on Darwin: evolution by descent and differential reproduction. All living things share a common ancestor and are getting differentiated. I would say it is the descent with modification: many hereditary characteristics that have different impact on the characteristics of organisms. (...) It is adaptation, survival of the fittest. A simple definition is the process of transformation by natural selection.
3- Neoclassic discourse. (n=6 / 35%)
The theory of evolution is a theory that explains the changes at a morphological and biochemical level of organisms from genetics. (...) The basic idea is that you have change in gene frequency (…) It has other processes: genetic drift, founder effect, random (...) mutation (...) The theory of evolution I basically split on a tripod: heredity, mutation and natural selection. (...)
4- Discourse of the distinction between 'development' and 'progress'. (n=3 / 18%)
Evolution has nothing to do with progress. (...) The theory of evolution is a theory of change, and not a theory of progress on a large scale. (...)

Figure 1- CSD to the question "In your own words, how would you summarize the "basics" of the theory of evolution?"

Question II - What are the controversial issues of the theory of evolution and how do you see them?

Figure 2 shows that three discourses were formed:

1. Controversies are part of daily academic practices and are related to aspects of evolutionary mechanisms and events – this discourse refers to time, pace and the relative importance of mechanisms and evolutionary events. It emphasizes topics that are still being discussed and reviewed by the scientific community.

2. There are no controversies regarding the theory but a lack of epistemological knowledge - controversies arise from peers' epistemological ignorance.

3. Controversies come from religions - controversies are outside academy.

1- Controversies are part of daily academic practices and are related to aspects of evolutionary mechanisms and events. (n=11 / 53%)
I think perhaps the point that is most at issue is the time in which evolution occurs. The time it takes natural selection to act. The rhythm. The relative importance of evolutionary events for evolution as a whole. We have issues where in certain species, forces are involved or not: if it is genetic drift or if it is natural selection. I think that these points are too specific. (...) One point that is very controversial is speciation. (...) The question of random. I think things are going very well. (...) Currently we discuss the influence of epigenetics (...) This is under discussion.
2- There are not controversies regarding the theory but a lack of epistemological knowledge. (n=6 / 35%)
I do not see controversial points in the theory of evolution. These are details within the scope of general theory. For me if we had a less scientistic attitude would be less harmful to science. (...) It is natural to have divergent views in science. (...) There is a lack of evidence for evolution: this is a limitation. Not that it invalidates, but makes room for extrapolations. I think the most contentious issue is the ability to test it. It's a circular thought, tautological.
3- Controversies come from religions. (n=5 / 29%)
It has thousands of disputes (outside academy). I can cite the origin of life, human evolution. Creationists are inventing pseudo controversies. One of these points is the punctuated equilibrium. It involves innocence and bad faith on the part of creationists when they try to invalidate the theory. I think among biologists there aren't many controversies. But these new trends show that the evolutionary process is more complex, and this is exploited by creationists to criticize the theory. (...)

Figure 2- CSD from the question "What are the controversial issues of the theory of evolution and how do you see them?"

Question III - What is the consensus regarding the theory of evolution?

Figure 3 shows that three discourses were formed:

1. Natural selection is a consensus – natural selection is still seen as a consensus in the theory of evolution.

2. The theory of evolution is a consensus although there are questions about the influences and dynamics of genetics - this speech highlights the importance of the theory of evolution to biology; however, it makes restrictions to a tendency towards privileging the Genetics area.

3. Genetic mechanisms are a consensus - this is a very specific discourse related to the experience of teachers in the Genetics area.

1- Natural selection is a consensus. (n=8 / 47%)
The idea of natural selection is a consensus. The general hypothesis that there is a variation and these variations are selected within an environment of living beings what causes an increase in survival chances. (...) The leading role of the environment: the environment acting on the selection is a consensus. (...) Natural selection, the survival of the fittest and the fact that natural selection is constantly changing are complete consensus.
2- The theory of evolution is a consensus although there are questions about the influences and dynamics of genetics. (n=10 / 59%)
The theory of evolution as a whole is a consensus. (...) The speciation, i.e. also the central mechanism "that species evolve" is very well structured. The importance of the theory of evolution itself. (...) The fact that a unifying theory. (...) Some people have spoken of epigenetic inheritance etc. as if it were a change in theory. (...) Geneticists took over the theory and it sacrificed the contribution of developmental biology. Huge phenotypic plasticity is ignored, for example, by geneticists. (...) The evolutionary theory, in short, was very “geneticized” (...).
3- Genetic mechanisms are a consensus. (n=6 / 35%)
The genetic basis of the theory is a consensus: the incorporation of heredity through population genetics, the understanding of gene biochemically, gene regulation, genetic drift and genetic determinism. The mitochondria and chloroplasts were bacteria, the question of speciation: these things are well accepted. It has many well-founded things, because evolution is central to biology.

Figure 3- CSD from the question “What are the consensus regarding the theory of evolution?”

DISCUSSION AND CONCLUSIONS

As Figure 1 shows the CSD to the question about the “basics” of the theory of evolution revealed the group’s common epistemological concerns, but they also showed a Darwinian and a neo-Darwinian view of evolution. Although the group shares common epistemological concerns, the Darwinian and neo-Darwinian CSD are mutually exclusive because professors adhered to either scientific discourse. As part of the methodology, the professors participated in a seminar. The group recognized themselves in all the results, but stressed that the neo-Darwinian discourse was the most correct one. The expression of two scientific discourses would have been a consequence of different everyday scientific activity that emphasizes, for some, more Darwinian aspects or neo-Darwinian, to others.

The group realized that these speeches were produced at a first moment of spontaneity and that they are interchangeable. But it could mean that genetic explanations are not always being taught integrated to evolution, as this explanation is strongly associated with a Neo-Darwinian approach. A survey conducted with these professors’ students revealed that evolutionary theory was represented by students in a similar way to those of their professors (Mannarino & Falcão, 2011).

Secondary school teachers are trained at the university and it is not difficult to wonder whether this oscillation around the integration of genetic explanations could impact future educational performance. It is also noteworthy that the Darwinian speech was the scientific discourse which had greater adherence among university students, while the Darwinian approach has found much more adherence with secondary school students (Valença & Falcão, 2012).

As Figure 2 and Figure 3 shows as for the controversy and consensus of the theory of evolution, the professors showed the perception that there is no controversy related to evolutionary theory. They also agree that questioning specific phenomena that have been discussed by scientists is a consequence of daily scientific activity, which allows the coexistence of competing hypotheses in search for further data and explanations for natural phenomena. But, it is important to mention that some aspects related to genetic mechanisms, such as the contradictory importance or periodicity of evolution mechanisms, were mentioned by the group as possible controversies because there are some current academic discussions related to them.

The group revealed the consensus of natural selection and genetic explanations confirming the proposed analysis of the discourse on the "basics" of evolutionary theory: without ruling out issues highlighted by the Darwinian approach, neo-Darwinism is the basis of evolutionary theory. There is also the recognition that the neo Darwinian approach is the most complete description of biological evolution processes because it integrates the set of genetic explanations.

However, there are specific aspects of biological evolution whose explanations do not need genetic information for understanding. This explains the two discourses encountered among the professors: Darwinian and neo-Darwinian. This finding reveals the contingency of scientific activities that were surrounding them at the moment. This data is relevant for our research because it offers elements to frame some educational difficulties already detected: students' difficulties with the conceptual basis of the theory of evolution. Considering that genetics is a strong empirical basis for the theory of evolution, our results suggest that some theoretical gaps could be minimized with the integration of genetic phenomena to evolutionary explanations.

In short, the Social Representations of the group revealed two discourses on the 'basics' of the theory of evolution (Darwinian and neo-Darwinian), and highlighted the role of genetics in evolutionary theory. If at first we sought to relate possible controversies within the theoretical basis of evolutionary theory to the difficulties of their conceptual understanding among secondary school students, we found what we call 'false controversy' caused by bias related to academic work, which possibly leads to difficulties in understanding aspects of the theory of evolution. In other words, influenced by the contingencies of their research activities, professors valued (or not) genetic mechanisms in evolutionary explanations and this fact is reflected in their classroom discourse. The effect of partial or incomplete views can produce theoretical gaps that only hinder the understanding of the theory of evolution.

These results suggest that expanded research on the teaching of the theory of evolution with different groups of research professors in other universities could help establish associations with the problems encountered in secondary education and expand the understanding of difficulties related to this essential theme in the biology curriculum. The source of difficulties of secondary school students regarding their understanding of the theory of evolution also has roots in the university, that is, in the context of teacher education.

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REFERENCES

Abrantes, P.; Almeida, F.P.L. (2006). Criacionismo e darwinismo confrontam-se nos tribunais... da razão e do direito. *Episteme,* v. 11, n. 24: 357-402.

Anderson, D.L.; Fisher, K.M.; Norman, G.J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of Research in Science Teaching,* 39:952-978.

Branch, G.; Mead, L.S. (2008). “Theory” in Theory and Practice. *Evo Edu Outreach*, I:287-289.

Cunninghan, D.L.; Wescott, D.J. (2009). Still More “Fancy” and “Myth” than “Fact” in Students’ Conceptions of Evolution. *Evo Edu Outreach*, 2(3): 505-517.

Lefèvre, F.; Lefèvre, A.M.C. (2003). *O discurso do sujeito coletivo: um novo enfoque em pesquisa qualitativa (desdobramentos)*. Caxias do Sul: EDUSC.

Mannarino, A.; Falcão, E.B.M. (2011). Discursos Darwnista e Neodarwnista: o vínculo inesperado entre professores e estudantes. *In: VIII ENPEC e I CIEC, 2011, CAMPINAS. VIII Encontro Nacional de Pesquisa em Educação em Ciências e I Congresso Iberoamericano de Investigación en Enseñanza de las Ciencias*.

Moscovici, S. (2003). *Representações sociais: investigações em psicologia social*. Petrópolis: Editora Vozes.

Richards, R. (2008). Philosophical Challenges in Teaching Evolution. *Evo Edu Outreach*, 1, 158–164.

Tidon, R; Lewontin, R.C. (2004). Teaching evolutionary bilogy. *Genetics and Molecular Biology*, 27(1):124-1.

Valença, C.R.; Falcão, E.B.M. (2012). Teoria da evolução: representações de professores-pesquisadores de biologia e suas relações com o ensino médio. *REEC- Revista Electrónica de Enseñanza de las Ciencias*, 11, 2, 471-486.

THE CONTRIBUTIONS OF THE COMPUTER MOLECULAR MODELING FOR CHEMICAL TEACHING: RESEARCH REPORTS

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Abstract: Molecular modeling is employed in the field of Computational Chemistry for decades. In teaching, the use of computers notably helps the development of visuospatial abilities as part of a system of perception of symbols that are typical of a field of Science. We consider that the interaction of students with molecular modeling can lead to the building of dynamic tridimensional mental models, producing a richer conceptualization of the chemical phenomena and imbuing the students with specific competences and the ability of higher order thinking. Our research took as epistemological referential the ideas of Larry Laudan, upon which we build up our theoretical referential choice as it connects scientific development to the growing capacity to solve problems. The theoretical referential that was used in our research is unheard before within the field of Chemical Education, the Cognitive Networks Mediation Theory (CNMT). The methodological referential built also was unheard of and starts with the epistemology of tacit knowledge of Michael Polanyi. The methodology able to reveal it has the main objective to identify and comprehend the depictive gesture of the students (non verbal speech) by means of gesture analysis. Therefore, we developed a variation of the Think Aloud technique, that we hereby name Report Aloud, and which consists in making the student report his reasoning process when he was facing the challenge of the resolution of the proposed problem. The verbal speech was also analyzed by Speech Analysis. Our main research result so far shows that the use of molecular modeling allows the student to acquire a dynamic view of the transformations processes in molecules, helping in the consolidation of visuospatial abilities and allowing the students the building of a more integrated understanding of chemical concepts around the energy concept that, usually, are historically treated as distinct.

Keywords: Chemical Education, Molecular Modeling, Cognitive Networks Mediation Theory, Computer-Based Learning, Extracerebral Cognition.

INTRODUCTION

This paper aims to describe the main results of our doctoral research that seeks to understand what the contributions of molecular modeling, as viewed as an extracerebral processing tool for learning chemistry concepts. The term molecular modeling may be understood as part of the chemistry that is "research of molecular structures and properties using computational chemistry and graphical visualization techniques, to provide a reasonable three-dimensional representation under a given set of circumstances" (IUPAC, 1997).

The literature in the Chemistry Education field created the consensus that some chemistry topics are difficult to understand by students. Many concepts of chemistry require a cognitive joint construction of symbolic representation and microscopic domains (Wu, Krajcik & Soloway, 2001). The study of chemical concepts from model building has been widely advocated by researchers at the Chemistry Teaching area, as opposed to "settle" curriculum, in which the contents are deposited without proper consistency (Gilbert, 2004). Therefore, the teaching of science from approaches that use models and modeling facilitates learning and developing scientific reasoning (JUSTI, 2009).

Many students still have difficulties in developing visuospatial skills, so important to the evolution of chemical reasoning (Wu & Shah, 2004). The use of models and modeling helps develop visuospatial skills. The role of these abilities have been reported in a consistent range of data demonstrating these skills to be the starting point for construction of three dimensional imagery.

Invariably, when we try to understand the functioning of a particular object or system, we need to create in our brain a similar representation to the object of study and think of a model that explains its operation, with specific rules. The next step is to imagine that working model and, finally, comparing the results imagined with reality (Moreira, 1996). Therefore, we can say we are doing a mental simulation (Monaghan & Clement, 1999) when we have the ability to mentally imagine a model in operation.

The term mental simulation is little explored in the literature of Chemistry Teaching area. However, the results of our study indicate that the moment at which a student interacts with a computational simulation of molecular modeling, it builds a mental representation analogous to the computational simulation. With that, it advances to build a mental model capable of explaining the operation of the simulation and starts to imagine in your mind this model in operation. From that moment, the student is conducting a mental simulation that endows greater ability to solve chemical problems.

Specifically in relation to molecular modeling, we believe that the student create a mental simulation when mentally models the behavior of a given chemical system, be it an atom or a molecule. The results of our research indicate that this ability to "perform" a mental simulation gives the student a greater ability to solve chemical problems such that: a) unresolved problems become problems solved b) solved problems become better resolved.

Given this scenario, and with the conviction of the potential of molecular modeling as a teaching tool, we seek to develop theoretical and methodological frameworks that allow us to study how students learn chemistry concepts when using the molecular modeling to solve chemical problems.

THEORETICAL-EPISTEMOLOGICAL REFERENCE

Among the rationalists and those who attribute a more social approach to the construction of scientific thought, we decided to choose Larry Laudan, linking the scientific development of the growing problem-solving skills, as an Epistemological Referential, since problem solving is the basis of our educational activities with molecular modeling. Furthermore, we use as a theoretical basis a unique reference for the field of chemistry teaching, CNMT – Cognitive Networks Mediation Theory (Souza et al., 2012). The most interesting premise of CNMT for our research is that the brain seeks external instruments able to complete its natural limitations of information processing. This mediation process results in the acquisition of a representational competence arising from the construction of new representations and drivers, greatly increasing the ability to process information in the brain. The CNMT is easily associated with Laudan's epistemology of problem solving (Laudan, 2011), which categorizes scientific problems as unresolved (previously), solved or anomalous.

In addition to the epistemological framework of Laudan, which underlies the choice of the theoretical framework, we also consider important to present the epistemology of Michael Polanyi (Polanyi, 1958) to underpin our methodological choice. Polanyi brings up the concept of tacit knowledge, implicit and inherent to each subject. And the implicit knowledge of our focus of attention, the construction of Polanyi are important in order to justify the methodology of gestural analysis as the main tool to uncover this implicit knowledge. Depictive gestures that we normally do when we are explaining how to solve a problem, as a rule, reveal the implicit knowledge used in solving the problem. Figure 1 shows a schematic of the theoretical and epistemological frameworks used.

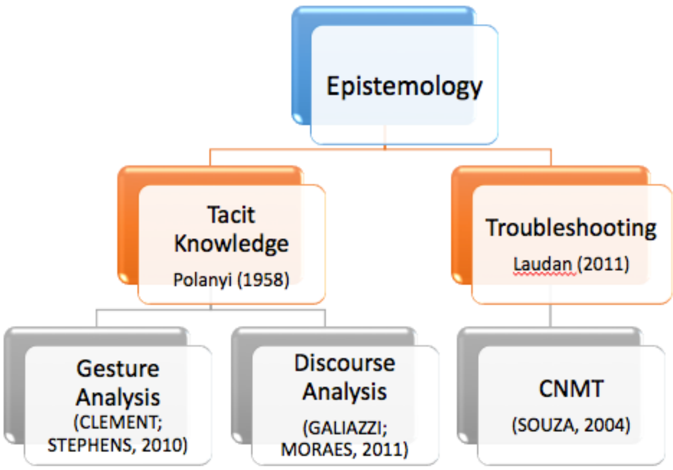

Figure 1: Theoretical and epistemological framework of the scheme used in the research.

CNMT, as a theory, built a set of concepts that draws our attention to the "external mechanisms of mediation" and "internal mechanisms of mediation" - bringing a different perspective when it comes to consider the so-called extra-brain cognition. In fact, the starting point of the construction of these concepts is the fact that the usage of electronic devices is made possible by a mediation process. So, it is natural to infer that these devices become external mediation mechanisms and that internal mechanisms are built by the subject over time and with the need to acquire new skills for the use of these devices.

These internal mechanisms are what make possible the use of external mechanisms and are called by the author of CNMT drivers, weaving an analogy to computing itself to an approach based on computer-brain metaphor of cognitive psychology (Bruner, 1983):

It is reasonable to assume that the internal mechanisms mediating function by producing a shell, or a 'virtual machine' that 'mirror' or 'represents' the external mechanism. This is a process necessary for establishing an interface between the brain and brain extra mechanism, but also allows, to some extent, a "emulation" at least part of external mechanisms in question. It follows, therefore, a partial internalization of external mechanisms, which helps explain why the skills remain increased even when external mechanisms are absent. (Souza, 2004, p. 81-82)

Vasconcelos and Oliveira (2012) made a categorization of the different mental representations, which highlight the similar mental representations, which are linked to concrete images and are called analogous or imagistic to be similar to the objects we perceive in our daily lives. These are imagistic mental representations we have special interest in this research, because these representations translate tacit knowledge of students.

Reading the context of our research under the CNMT referential, when students are in extra cerebral mediation process with a computer simulation of molecular modeling, imagistic mental representations analogous to the simulation of content are created in the cognitive structure of students. The creation of these representations occurs from the process of acquisition of specific drivers. Some of them are necessary for the student to interact with the external mechanism, comprising its functioning. But there are other drivers that are formed in this process from the time the student may understand the operation of the simulation and begins to interact with its scientific content so that new knowledge is acquired. The identification of these drivers is the objectives of our research.

METHODOLOGY

The research methodology, also unprecedented for the area, was built performing four separate experiments: two pilot trials and two definitive experiments. For such, the starting point was the combination of the epistemology of tacit knowledge of Polanyi (Polanyi, 1958) with the gesture analysis (Clement & Stephens, 2010; Monaghan & Clement, 1999), for unraveling the non-verbal speech of students; and the discursive analysis (Galiazzi & Moraes, 2011), to evaluate these verbal speech. Tacit knowledge is the fundamental basis of analysis, along with explicit knowledge student speech during the interviews. For this article, we shall use data from two definitive experiments.

When faced with a problem-solving activity, the student will evoke a set of previous knowledge, and many of these are tacit. The analysis of tacit knowledge, which is presented as mental images, is not realized if it is not transformed into explicit. Thus, tacit knowledge is transformed into explicit by specific elements, direct and indirect, of student speech, especially in the form of descriptive gestures.

The methodology thus constructed is framed in Figure 2.

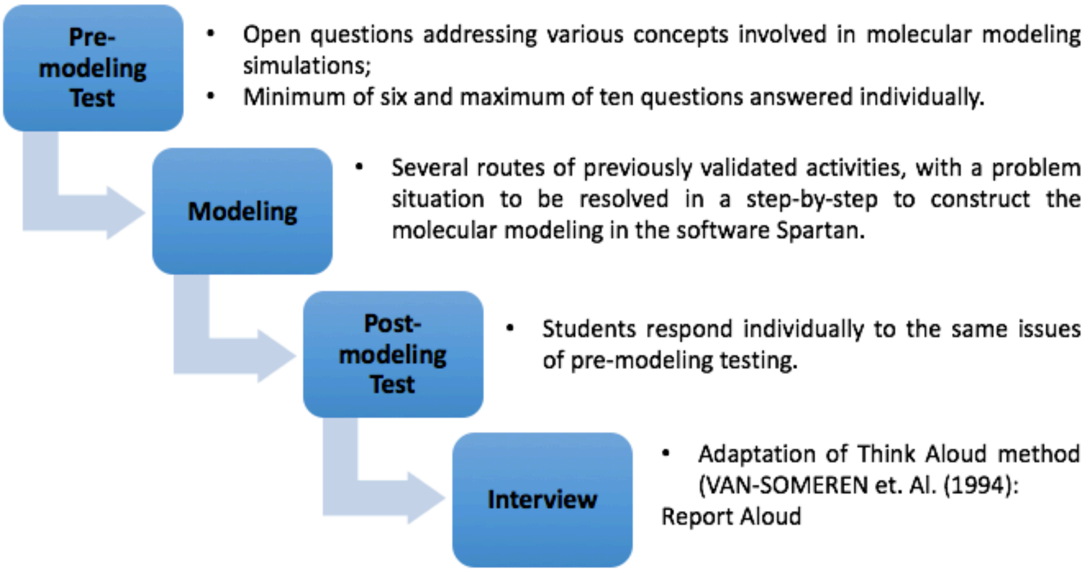

Figure 2: Description of the methodological procedures.

Upon finishing the molecular modeling activity, where students construct and perform the simulations, each student must make an assessment on the level of convergence between the modeling result and the mental modeling previously made to the simulation, performing reflection on the possible differences.

The Report Aloud protocol, developed by us for this research differs from Think Aloud protocol only when the researcher seeks to understand the students' reasoning process to solve problems. While the Think Aloud method exploits the thought processes of students in the act of solving the problem, the Report Aloud method does after the student has already solved the problem. Thus, there isn't interference of the researcher in the student's own thinking process.

RESULTS

After conducting two pilot tests and two definitive, we chose to present in this paper the most representative result arising from each of the definitive and unprecedented experiments to the area. The first definitive experiment was carried out with six graduate students in chemistry and had the following methodological sequence: pre-modelling individual test; modeling; post-modelling individual test and interview. The pre- and post-modeling tests had thirteen questions that addressed the content of the simulations, namely: molecular geometry, molecular polarity and dipole moment, conformational analysis; organic reactions (nucleophilic substitution of second order and Diels-Alder).

From the first definitive experiment, we bring the concept of dynamic vision of the transformations, as shown in Figure 3, below.

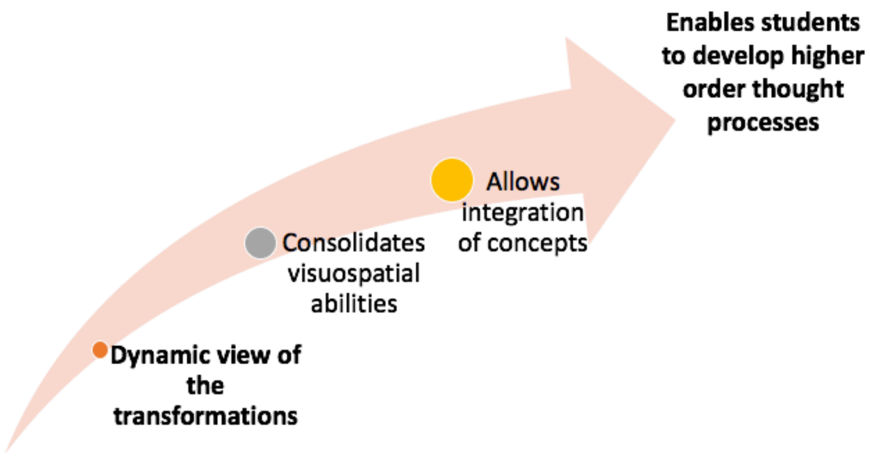

Figure 3: Results of research arising from the first definitive experiment.

In general, we may say that the use of molecular modeling software allowed students to gain a more dynamic view of the transformation processes present in the molecules that: a) helped in the consolidation of visuospatial abilities of students and b) gave the opportunity for students to build a more integrated view of concepts that, as a rule, are treated separately. That enchainment creates the conditions so that the student may develop higher-order thinking processes (Kaberman & Dori, 2007).

Figure 4 shows a sequence of depictive gestures performed by the students in the interviews.

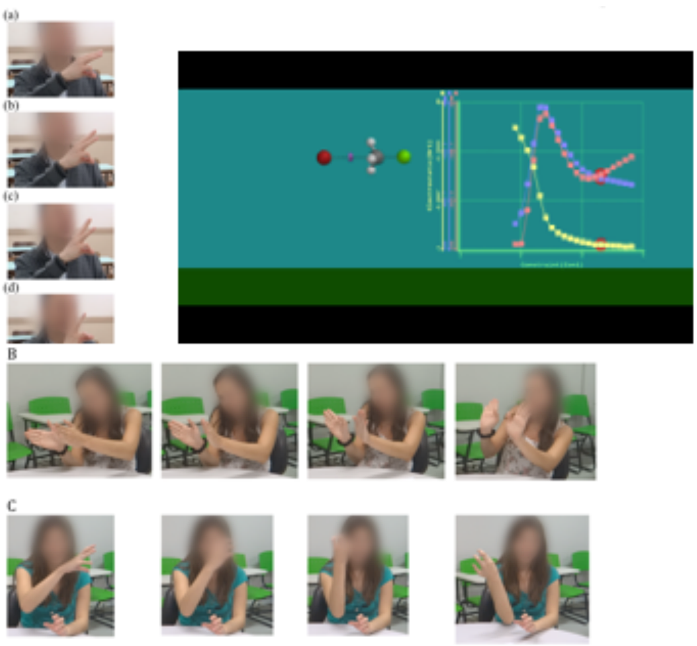

Figure 4: Descriptive gestures involving nucleophilic substitution reaction mechanism of the second order (S_N2).

Descriptive gestures present in Figure 4 were made by students in both definitive experiments to explain how students solve a chemical problem associated with the classic SN2 reaction mechanism in which there is inversion of configuration of the hydrogens of the methyl chloride caused the replacement of the ion chloride for the bromide ion in the molecule. We stress that the first definitive experiment was performed with undergraduate and the second high school students. In both cases the depictive gestures in this interview were the same.

This research result was very striking, because high school students reported in their pre-test to have no idea how the mechanism of this reaction occurred, especially the inversion of configuration. Upon completion of the simulation of molecular modeling, all managed to mentally simulate the steps of the mechanism, building the dynamic vision of transformation and thereby developing higher-order thought processes. In the interview, we clearly see that there was imagistic gaps in the students that were somewhat completed by the usage of the molecular modelling software, allowing them to make use of the concept of energy in an integrated manner.

From the second final experiment, we bring an important contribution on the concept of learning as outlined in Figure 5. The second definitive experiment included six students of a technical course in chemistry and had the following methodological steps: pre-modelling individual test; pre-modeling interview; modeling; post-modelling individual test; post-modelling interview. The tests contained nine questions that addressed theoretical aspects of chemical concepts used in the simulations. The contents addressed were: molecular geometry, molecular polarity and dipole moment, conformational analysis; organic reactions of SN2 type.

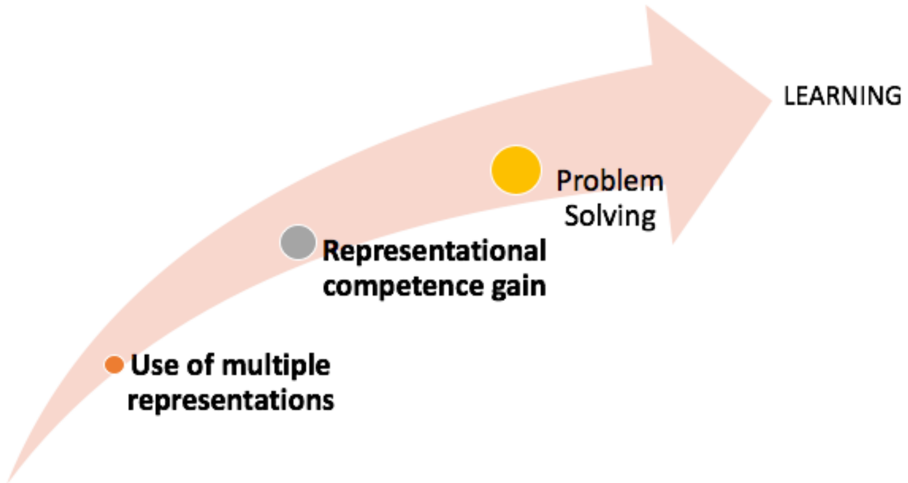

Figure 5: Results of research arising from the second definitive experiment.

All along the path in this study, we observed that, in the extent that the molecular modeling is used as a teaching tool, students create multiple representations and begin to transit between these multiple mental representations about the same object or phenomenon according to the need or convenience.

The use of multiple representations endows students with a broader theoretical tools and representational competence whose direct consequence is a better problem-solving capacity. When a student solves a scientific problem that was, to him, considered anomalous, as it was not possible to be solved with the knowledge that he had, he is then regarded as a solved problem from the competence gain acquired by molecular modeling tools. Even problems that were considered as solved, in some cases, were viewed as better resolved from an information processing gain afforded by interaction with molecular modeling, as shown in Figure 6.

In this example, we bring answers of two students from the second definitive experiment, the student could not answer the pre-test modeling to a question requesting an explanation of the mechanism of the SN2 reaction. After performing molecular modeling, the student could solve the problem in the post-modeling test, which ceased to be anomalous to be a solved problem. The second student presented in the pre-test , a poor and wrong representation of the geometry of the carbon tetrachloride molecule, whereas in the post-test test, we identified a substantial representational and conceptual improvement.

For the student, the problem in the pre-test modeling was resolved. However, after performing the simulation of molecular modeling on the representations of the molecular geometry, the student clearly improves its theoretical tools and starts to solve the problem with representational and conceptual gain, as it changes the geometry to the correct octahedral grouping and draws a representation of connections out of the plane.

GENERAL CONSIDERATIONS

Mental images are fundamental to the understanding of the phenomena studied, as we believe it is not possible to solve problems without the student building mental images. They are the starting point, that allow students to construct a dynamic vision of the transformations. This dynamic vision of the molecular transformation process seems to lie mainly in the dynamic view of the chemical transformations, in filling in imagistic "gaps" - particularly with regard to the transition states and their relation to existing images - and the integrated use of the concept of molecular energy.

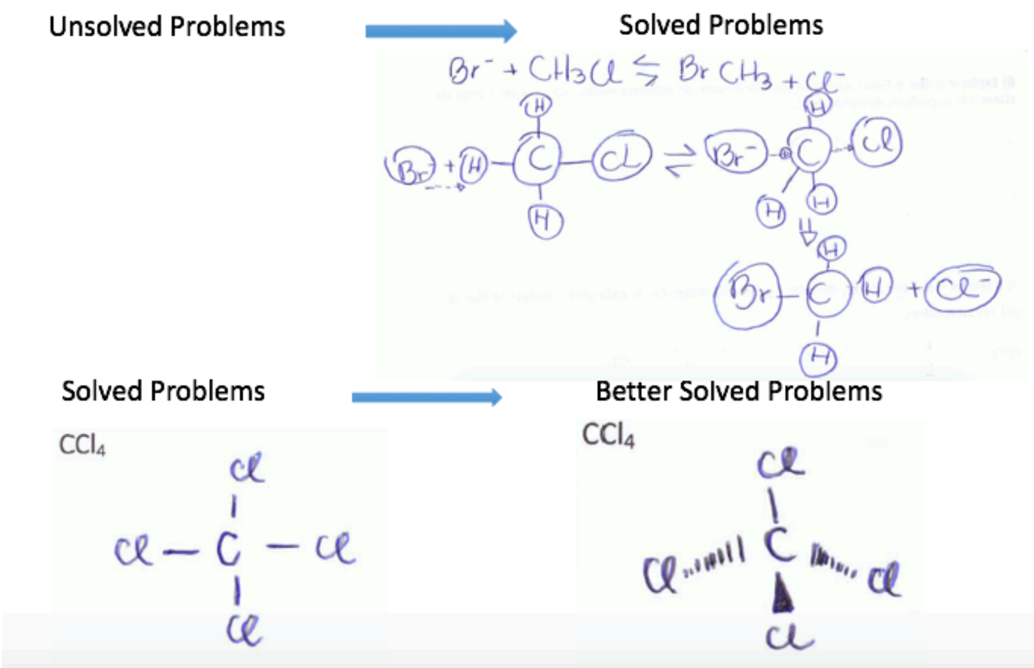

Figure 6: Comparison of problem solving between the pre-test and post-modeling modeling.

These factors allow the student to construct mental simulations of chemical transformations and model these transformations. Moreover, students cognitively recognize that molecular modeling is the tool of choice for the investigation of chemical processes unknown to them.

From this point, the student may begin to realize, for example, that there is a close relationship between the structure of matter, its properties and energy. With proper guidance, the student is able to start building integrated concept of energy and think in terms of molecular modeling, developing high order thinking skills.

After long immersion in the search results and the theoretical constructs of epistemology of problem solving of Laudan and CNMT de Souza, we may define that **learning is a competence gain through the acquisition of new representations and drivers, in the direction of a greater capacity for problem solving**.

Both problems already considered resolved, as unresolved problems; both simple problems, as the more complex problems. In this case, the student tends to adopt this new concept to realize that it is more effective in solving problems. This fact, to Laudan, is one of the landmarks of scientific progress and, for us, one of the landmarks in science learning.

REFERENCES

Bruner, J. S. (1983). *In Search of Mind*. New York: Harper & Row.

Clement, J. J., & Stephens, A. L. (2010). Documenting the use of expert scientific reasoning process by high school physics students. *Physics Education Research*, *6*(2), 20122–1 – 20122–15.

Galiazzi, M. C., & Moraes, R. (2011). *Análise Textual Discursiva[Textual discursive analysis]*. Ijuí: Editora Unijuí.

Gilbert, J. K. (2004). Models and modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, *2*(2), 115–130. Retrieved from http://www.springerlink.com/index/H4237K87X0287328.pdf

Iupac. (1997). Glossary of Terms Used in Computational Drug Design. *Pure & Appl. Chem.*, *69*(5), 1137–1152.

Justi, R. da S. (2009). Learning how to model in science classroom : key teacher ' s role in supporting the development of students ' modelling skills. *Educación Química*, 32–40.

Kaberman, Z., & Dori, Y. J. (2007). Question posing, inquiry, and modeling skills of chemistry students in the case-based computerized laboratory environment. *International Journal of Science and Mathematics*, *7*(3), 597–625.

Laudan, L. (2011). *O Progresso e Seus Problemas: rumo a uma teoria do crescimento científico [Progress and its problems: towards a theory of scientific progress]*. Tradução Roberto Leal Ferreira. São Paulo: UNESP, Editora.

Monaghan, J. M., & Clement, J. J. (1999). Use of a computer simulation to develop mental simulations for understanding relative motion concepts. *International Journal of Science Education*, *21*(9), 921 – 944.

Moreira, M. A. (1996). Modelos Mentais [Mental models]. *Investigações Em Ensino de Ciências*, *1*(3), 193–232.

Polanyi, M. (1958). *Personal Knowledge: towards a post-critical Philosophy*. Chicago: The University of Chicago Press.

Souza, B. C., Silva, A. S., Silva, A. M., Roazzi, A., & Silva, S. L. C. (2012). Putting the Cognitive Mediation Networks Theory to the test: Evaluation of a framework for understanding the digital age. *Computers in Human Behavior*, *28*(6), 2320–2330. http://doi.org/10.1016/j.chb.2012.07.002

Souza, B. C. de. (2004). *A Teoria da Mediação Cognitiva: Os impactos cognitivos da Hipercultura e da Mediação Digital [The theory of cognitive mediation: The cognitive impacts of hyperculture and digital mediation]*. 282p, Tese (Doutorado em Psicologia) - Centro de Filosofia e Ciências Humanas, Universidade Federal de Pernambuco, Recife. Retrieved from http://www.liber.ufpe.br/teses/arquivo/20040617095205.pdf

Vasconcelos, J. L. C., & Oliveira, R. V. (2012). Representações Mentais: Uma abordagem Cognitivista [Mental representations: A cognitivist approach]. *Revista de Saúde Mental Em Foco*, *1*(1).

Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching*, *38*(7), 821–842. http://doi.org/10.1002/tea.1033

Wu, H.-K., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education*, *88*, 465–492.

LEARNING ABOUT MEASUREMENT UNCERTAINTY IN AN ALTERNATIVE APPROACH TO TRADITIONAL ERROR CALCULATION

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Abstract: The handling of data in scientific laboratory work and in the learning of science always also involves the consideration of the data's limited precision. Yet, both school curricula and teaching practice often neglect the explicit reflection on it, even though experimental work is seen as a fundamental part of teaching science. Secondly, teaching practice mainly refers to the traditional frequentist approach of error analysis that holds a considerable amount of mathematical inconsistencies. The modern recommendation of the ISO-Guide to the Expression of Uncertainty in Measurement (GUM), offers an alternative approach that is founded on a probabilistic, Bayesian informed interpretation of measurement. It represent the information gained from measurement in terms of probability density functions (pdfs) over an interval of values that can reasonable be attributed to the measurand. Values for the best representative and for the width of the interval can be derived to characterize the distribution. Over the past ten years considerable approaches have been developed for the teaching of measurement uncertainty with respect to GUM for both university and secondary education (e. g. Buffler 2008, Heinicke 2012, Hellwig 2013). To support a holistic understanding of the nature of measurement data and uncertainty and the propagation of uncertainty, however, we found that it is necessary to illustrate how the intervals or pdfs of the input quantities actually form the width and shape of the resulting distribution for the quantity under consideration. Based on our studies that assessed both students' understanding of data evaluation as well as their ability use probability representations, we developed a software that graphically transfers pdfs of input quantities via a given equation into a pdf for the desired quantity. The software was tested with both university students as well as secondary graders. The software and results of the testing will be presented.

Keywords: measurement uncertainty, error, probability, introductory laboratory, data evaluation

INTRODUCTION

Taking readings and evaluating data in the science laboratory will always include a consideration of uncertainty, i.e. the limitations to the reliability of data. Unfortunately, *error discussion* or *error analysis* is commonly received as a time-consuming and dispensable effort with respect to the knowledge gain it offers. On the contrary, a consideration of the error (or uncertainty) of data indeed holds valuable information about the measuring process and the result obtained and would have to play a role in any experimental decision during the process of measuring. Taking different experimental situations into account, Figure 1 shows that uncertainty has to be taken into account for any of the required decisions: If a reference value is given (as it commonly is the case in introductory laboratory courses) only a consideration of the results' uncertainty will enable the observer if the result obtained and the target value are in agreement. The same is true, when two different groups compare their results as pure point-like numerical values cannot be compared without reference to some measure of tolerance. Further, uncertainty decides about the number of adequate numerical figures when noting a result or indicates if a repetition of measurement would offer valuable information.

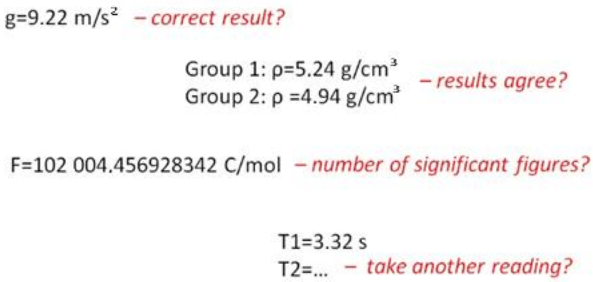

Figure 1. Experimental situations where a decision has to be made that requires the consideration of uncertainty.

The consideration of uncertainty however, reaches far beyond the laboratory. In our day-to-day lives we are surrounded by data that demand interpretation but that usually do not come with information about their reliability. Scientific literacy here denotes a competence needed for a critical participation on society‘s issues.

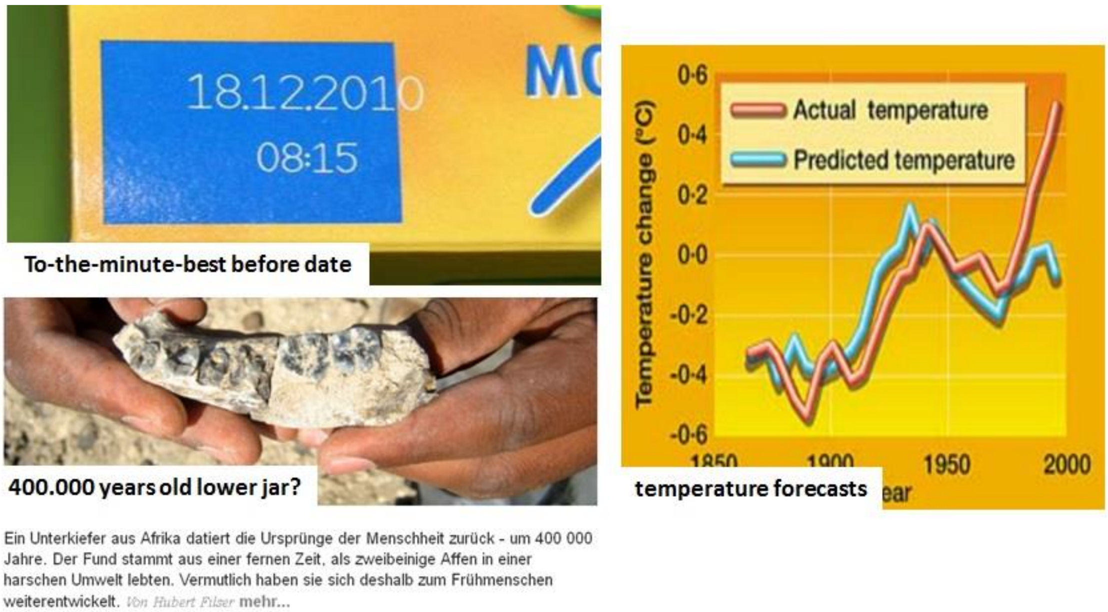

Figure 2. Examples of data in our day-to-day lives that demand a consideration and interpretation of their uncertainty.

Thus, the handling of data in scientific laboratory work and in the learning of science always also involves the consideration of the data's limited precision – explicitly or implicitly. Traditionally, this limited precision is called *error* and its handling *error calculation*. Yet, the traditional frequentist approach to error analysis holds a considerable amount of mathematical inconsistencies and experimental loopholes (Heinicke 2012). Different studies over the last three decades (e.g. Seré and Larcher (1993), Lubben and Millar (1996), Buffler *et al.* (2001), Garratt *et al.* (2000)) have offered valuable insight into the concepts of students concerning the handling of measurement data and uncertainty and their resulting struggle with the traditional approach. They have informed a number of new approaches to the introductory laboratory to help students overcome some major difficulties concerning their understanding of the mathematical methods involved. In consequence, considerable approaches have been developed lately for the teaching of measurement uncertainty for both university and secondary education (e. g. Buffler 2008, Heinicke 2012, Hellwig 2013) that implement an alternative approach to data handling in terms of the ISO-Guide to the Expression of Uncertainty in Measurement (GUM).

The GUM was published in 1993 as an alternative to the traditional approach by the JCGM. While it has found its way into applications of scientific research and technology it is still largely unknown in science teaching both at school and university level. In contrast to traditonal error analysis, the GUM's approach is founded on a probabilistic, Bayesian

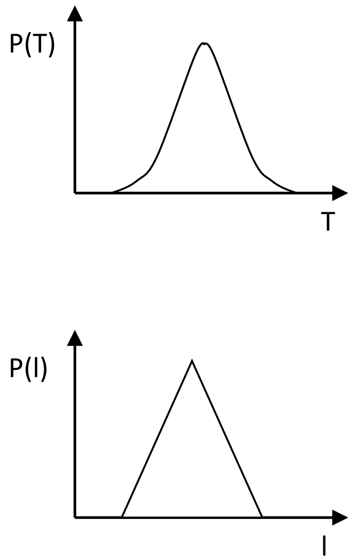

Figure 3. Examples of probability density functions to model informations about a certain measurand. Here: Information about periodical time T after several measurements and length of the pendulum l after measuring once with a meterstick.

informed interpretation of measurement and the nature of measurement data and represent information gained from measurement in terms of probability density functions (pdfs) over an interval of values that can reasonable be attributed to the measurand. Values for the best representative and for the width of the interval can be derived to characterize the distribution of possible values. For example, the gravity acceleration *g* can be established by measuring both length *l* and the periodic time *T* of a pendulum. Supposedly, *T* is measured a number of times and the datas' distribution can best be represented by a probability density function (pdf) as shown in the first example in Figure 3. The length *l* of the pendulum may have been measured once and its result represented in terms of a triangular distribution as shown in the second example of Figure 3. Quantities like the best value or its uncertainty can be derived from the pdfs by reaching an agreement about the best representative and a standardized measure for its uncertainty (e.g. taking the mean or mode and a standard uncertainty to a level of confidence of e.g. 68%).

Likewise, a study on the correspondence between the *reasoning on* and *reasoning in* action showed, how the theoretical reasoning about data evaluation and error handling in many cases differs significantly from the actual performance of students when it comes to real laboratory exercises (Heinicke & Riess 2012, see also Coelho & Séré 1998 and Kanari & Millar 2004). This corresponds to the finding, that prior instruction into data evaluation is commonly done theoretically on simplified examples and constructed data sets. Approaches to overcome this gap have been discussed in (Heinicke & Riess 2012).

We subsequently found, that another gap exists in the handling of measurement data and uncertainty of the approaches mentioned above. It occures because it is not only the quantities that were measured directly, that need to be represented in terms of pdfs. In order to establish a holistic concept, also a resulting quantity calculated from those needs to be represented in the same manner. Until now and in the absence of supporting formats, all concepts named above calculate final results, e.g. the gravity acceleration *g* from *T* and *l*, and their uncertainties by transferring the pdfs of the input quantities into the values of best representative and uncertainty that can be computed into the respective values for *g*. The result for *g* is thus established in terms of a best value and a measure for its uncertainty, consequently loosing the information about the width and shape of *g*'s pdf. Thus, the clarity of the understanding of a measurement result in terms of an interval of possible values in these approaches is limited.

METHOD

In our approach and research we therefore tackle both problems: The gap between experimental measurement and theoretical data evaluation and the inconsistency in the usage of pdfs. Based on the studies described above as well as assessments of students understanding how to draw und interpret graphical representations of probability and pdfs, we developed a software to support data evaluation in the immediate experimental context following the approach of GUM. The software allows both the immediate representation and propagation of data in the experimental context as well as a clear convolution of pdfs of the input quantities to a pdf of the quantity under consideration. The approach clearly differs from traditional error calculation or common evaluation routines in the introductory year laboratory as Figure 4 shows. The first quadrant shows a point-value approach where only numerical values of the input quantities determine the result of the quantity under consideration. The

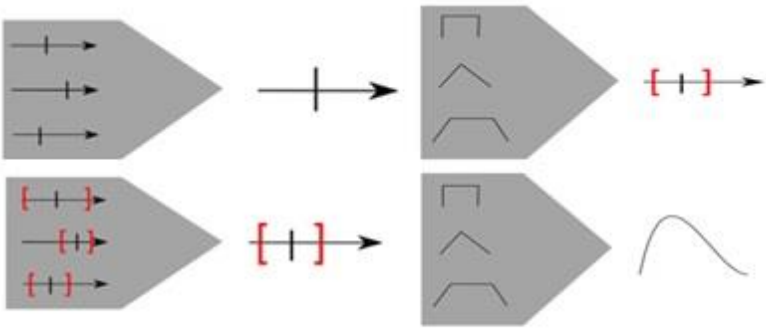

Figure 4. Comparison of different approaches to error handling: traditional point-value approach, interval-approach e.g. using error propagation, pdf-approach reducing information to atsandardized intervals and pdf-approach faolding all information into a pdf for the quantity under consideration.

second depicts common traditional error calculation using e.g. error propagation to determine the width of an error-interval using error-intervals of the input quantities. Thirdly, all available information about the input quantities is displayed in terms of adequate pdfs. The GUM then offers guidelines how to reduce each pdf to a standardized interval in order to calculate an interval for the resulting quantity using similar calculation routines than before in the *uncertainty propagation*. The fourth example represents the way discussed in this paper. The software that we developed folds the obtained pdfs of the input quantities using their scientific interrelation and through a Monte Carlo process produces a resulting pdf for the quantity under consideration (see also Figure 5 for an example: determination of g with a pendulum).

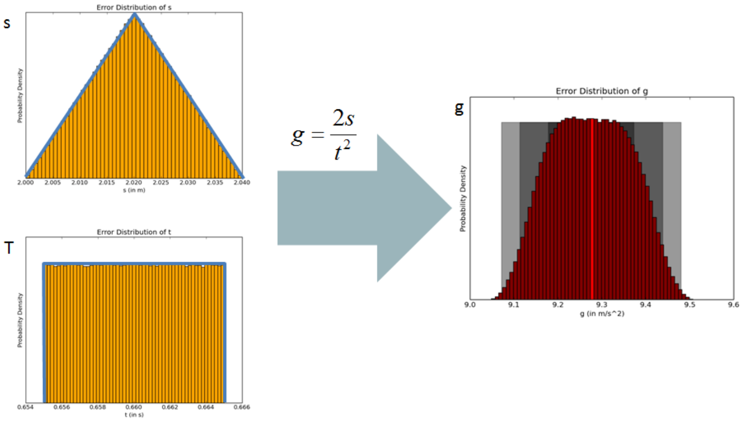

Figure 5. screenshot of the software folding pdfs of the input quantities to a resulting pdf of the quantity of consideration.

The software we designed was thereby based both on the GUM as well as on previous empirical studies. More than 250 first year students in physics laboratories and about 100 secondary students aged 14-16 years were assessed for their views on the handling of data in written probes based on an instrument by Buffler et al. (2001). Another 50 secondary and 25 university students were also assessed in another written probe for their ability to interpret and draw graphical representations of probability. The software is currently undergoing the first testing in the physics introductory laboratory at the university of Munster, Germany (students N=15). The free software is currently only available in a German version under the address of: gumcertainty.de. The tested and optimized software in both German and English will presumably be available in a free online version by summer 2016.

RESULTS AND CONCLUSIONS

The developed software mainly aims at an application at upper secondary and university level. Currently it is being tested in the introductory laboratory at the University of Muenster.

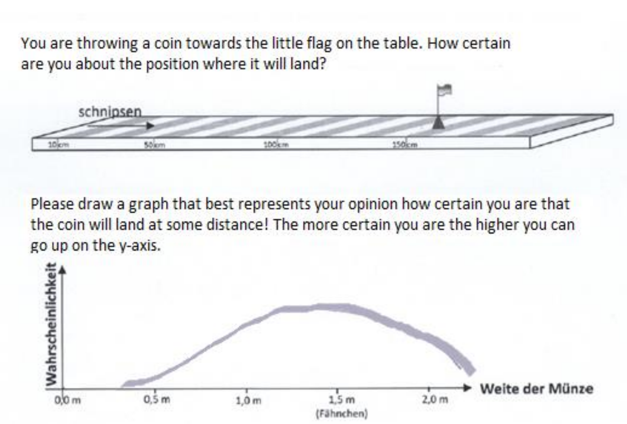

Figure 6. Example for a pdf drawn by a 8th grade student to depict the level of confidence to throw a coin a

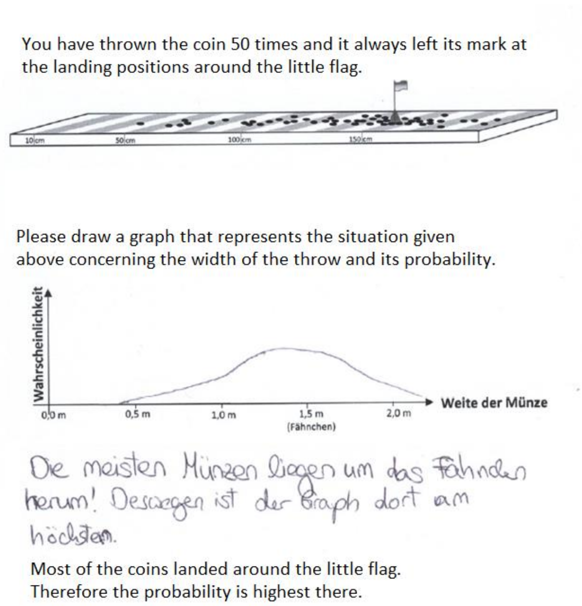

Figure 7: Example of a pdfdrwan by another 8th grade student to model a gven situation of a repeated throwing of the coin.

First tests on the developed software also indicate that the software indeed supports the students' understanding of both intervals as a representation of a measurement's result as well as the propagation of the input quantities' intervals or pdfs into a coherent information about the final quantity under consideration. A pre-post interview study is yet to be evaluated, however first responses of students show a high preference for this approach over traditional error calculation and a better performance in understanding the nature of measurement, measurement data, uncertainty and the evaluation procedures involved. Thus, our work provides an example for an alternative approach to data handling and evaluation following the GUM guidelines that aims at the intuitive understanding of students of probability and its graphical representation. Beyond the usage on upper secondary and university level we also started to investigate the potential of the approach in lower secondary grades. An assessment on the students' understanding of graphical representations of probability showed a high ability and reasonable intuitive understanding of the matter (see also Petrosino, Lehrer & Schauble 2003). According to our study even younger students (8^{th} grade) were already able to draw and modify pdfs on their own as well as interpret those that were given.

For this study a day-to-day life context was chosen where the students were asked to transfer the given information or their own ideas into a two-dimensional graphical representation displaying both values that could reasonably be attributed to the quantity under consideration as well as a representation of the corresponding level of confidence they could attribute to each. The previous results indicate that modern error calculation based on the probabilistic approach of GUM and the visualization represented by the software can be used for learners both at school as well as university level.

REFERENCES

Buffler, A., Allie, S., Lubben, F., Campbell, B. (2001). The development of first year physics students' ideas about measurement in terms of point and set paradigms, *International Journal of Science Education, 23*(11), 1137-1156.

Buffler, A., Allie, S. & Lubben, F.(2008). Teaching measurement and uncertainty the GUM way. *The Physics Teacher*, *46*, 2008, 539.

Coelho, S. M. & Séré, M.-G. (1998). Pupils' reasoning and practice during hands-on activities in the measurement phase. *Research in Science and Technological Education, 16(1)*, 79-90.

Garratt, J., Horn, A. & Tomlinson, J. (2000). Misconceptions about error. *University Chemistry Education, 4(2),* 54-57.

Heinicke, S. & Riess, F. (2012). Missing Links in the Experimental Work In: L. Maurines & A. Redfors (Eds.), *ESERA 2011 Proceedings*.

Heinicke, S. (2012). Aus Fehlern wird man klug. Berlin: Logos.

Hellwig, J. (2013).Messunsicherheiten verstehen. Dissertation http://www-brs.ub.ruhr-uni-bochum.de/netahtml/HSS/Diss/HellwigJulia/diss.pdf.

Kanari, Z. & Millar, R. (2004). Reasoning from data: How students collect and interpret data in science investigations. *Journal of Research in Science Teaching, 41(7),* 748-769.

Lubben, F., & Millar, R. (1996). Children's ideas about the reliability of experimental data. *International Journal of Science Education, 18*, 955-968.

Petrosino, A., Lehrer, R. & Schauble, L. (2003). Structuring error and experimental variation as distribution in the fourth grade. *Mathematical Thinking and Learning, 5(2-3),* 131-156.

Séré, M.-G. & Larcher, C.: Learning the statistical analysis of measurement errors. *International Journal of Science Education, 15*, 427-438.

UNDERSTANDING OF PHOTOSYNTHESIS CONCEPTS RELATED TO STUDENTS' AGE

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Abstract: In Croatian schools, the complex photosynthesis concept is presented several times during primary and secondary school, each time with more details. In the present study, we aimed to investigate how the students' understanding of the basic photosynthesis concepts increases during the schooling period, and is it enhanced by gradual introduction of new contents. The present study was conducted on 269 students from 6 schools and 35 students preparing to be biology teachers. To test the students' conceptual understanding, we implemented a question about the trends of O_2 and CO_2 concentrations during the night. It was expected that the question would lead students to a correct explanation of photosynthesis. However, students of all age groups gave mainly incomplete explanations. The best result was achieved by youngest participants (aged 11, who relied on the freshly acquired and well trained, but reproductive knowledge. The answers of older students (aged 15, 17 and 22) included more detail about the light-dependent and light-independent reactions, suggesting that they developed misconceptions (e.g., a belief that "oxygen is produced in Calvin cycle during the night" and that "CO_2 converts to O_2"). Students' explanations indicate the consistency of their understanding of photosynthesis, which does not change with gradual introduction of new contents as they get older. The observed misunderstandings could be associated to the cumulative introduction of the complex theoretical contents withoutresearch-based learning. As well, the misconceptions could point to inadequate time dedicated to establishing connections between students' pre-conceptions and novel information. Our research results might be a strong argument supporting the upcoming change in the Croatian national curriculum.

Keywords: photosynthesis, conceptual understanding, age groups

INTRODUCTION

The process of photosynthesis contains many interrelated conceptual components so it causes students' conceptual understanding difficulties (Özay & Öztas, 2003). If the teaching is merely reduced to description of processes and denomination of terms and concepts, it results in poor knowledge retention and formation/retention of misconceptions throughout the education (Canal, 1999). In Croatia, photosynthesis is taught several times during formal education. Considering the modest success of Croatian students regarding the acquisition and retention of the overall biological knowledge (Garašić et al., 2012), the aim of this research was to determine if there is a progress in understanding of photosynthesis. As students' overall knowledge grows with school age (Magntorn, 2007), it can be assumed that the expansion of learning would improve their conceptual understanding.

METHODS

The present article includes the analysis results for only one of five questions used to examine the basic concepts of photosynthesis. The question deals with changes of the amount of oxygen and carbon dioxide around the plant during the night (Figure 1). After filling the conceptual table, students should have added an explanation for their table answers.

At 7PM Mary covered her potted plant with a plastic bag. She tied the bag around the stem and made sure that the plant was completely wrapped to unable the air to flow in or out of the bag (see figure on the right). The plant stayed in the dark during the night. At 5AM Mary checked what happened with the gases in the bag.

In the table below, assign + to each statement you consider correct regarding the concentration of the gases (oxygen, carbon dioxide) within the plastic bag.

Gas	is increased	is reduced	remained the same
The amount of oxygen			
The amount of carbon dioxide			

Explain your answer.

Figure 1. The question posed to students of all age groups.

The question (Figure 1) was posed to 4 age groups of students, who were, at that time, learning about photosynthesis. The 4 groups represented students at different stages of the learning process – first group consisted of the 11-year-old students, second of the 15-year-olds, third of the 17-year-olds, whereas fourth group consisted of university students aged 22. The sample of the 11-, 15- and 17-year-olds was composed of 269 students attending 6 different schools. The sample of the university students was comprised of 35 students preparing to be biology teachers.

Each observed lesson followed the content framework presented in textbooks, by applying teacher-centred approach based on conversation, narration and figure demonstration. The exam, containing our test-question was conducted three days after learning about photosynthesis.

In following analyses, student's explanations were coded according to the criterion of contextual appropriateness to the relevant biological meaning, in order to categorize students' answers. For the statistical analysis, we used Spearman's rho (ρ) to establish the extent to which both parts of the question (i.e., table answers and their explanations) were consistent and correct, and the non-parametric Mann-Whitney U-test to compare the success of the individual age groups.

RESULTS

For the first part of test-question (*O_2 is reduced, CO_2 increases),* significantly more correct answers originated from the 11-year-olds than from the older students (Figure 2). The overall correlation coefficient ($\rho = 0.604$) between the accuracy of the answers given within the table and their explanations indicates that the consistency within the students' answers is moderate and it does not change with the students' age (Figure 3). In older age groups, incorrect answers prevailed (70%), and the percentage of correct answers was equal among 15- and 17-year-olds. The consistency of the students' answers did not change with adding new contents (Figure 3). 40% of students successfully filled the conceptual table, but only a half of them gave the correct explanation (Figure 4). By answering the table, students aged 11 showed significant difference compared to older students (Figure 5).

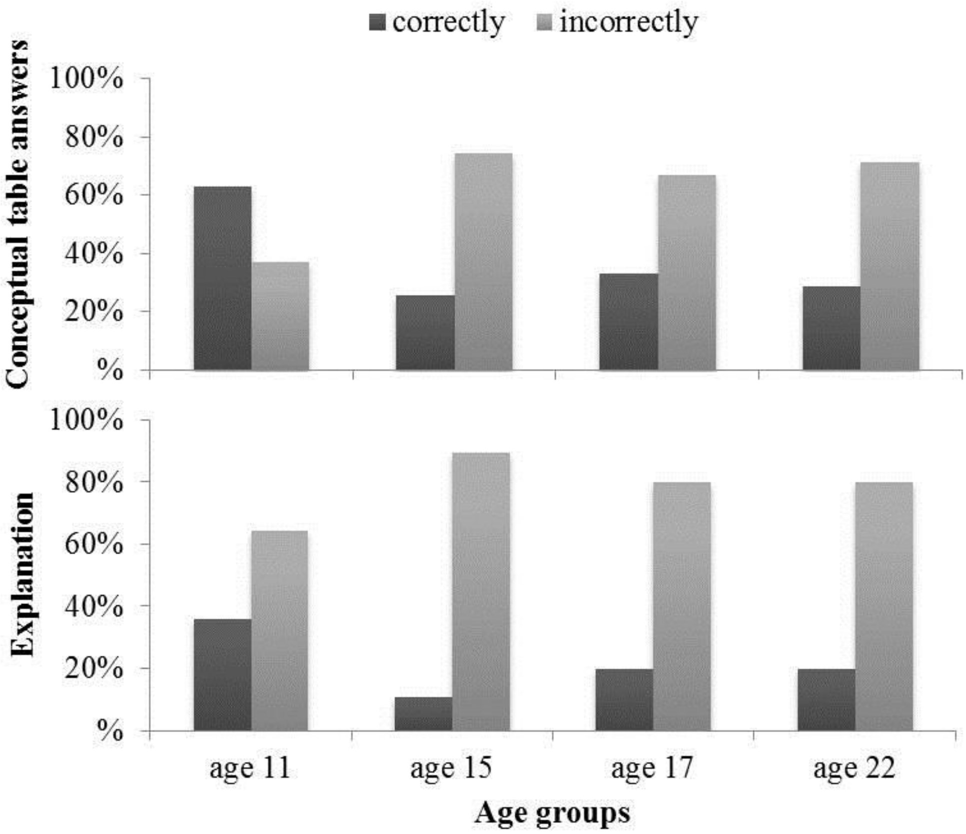


Figure 2. Students' answers according to age groups.

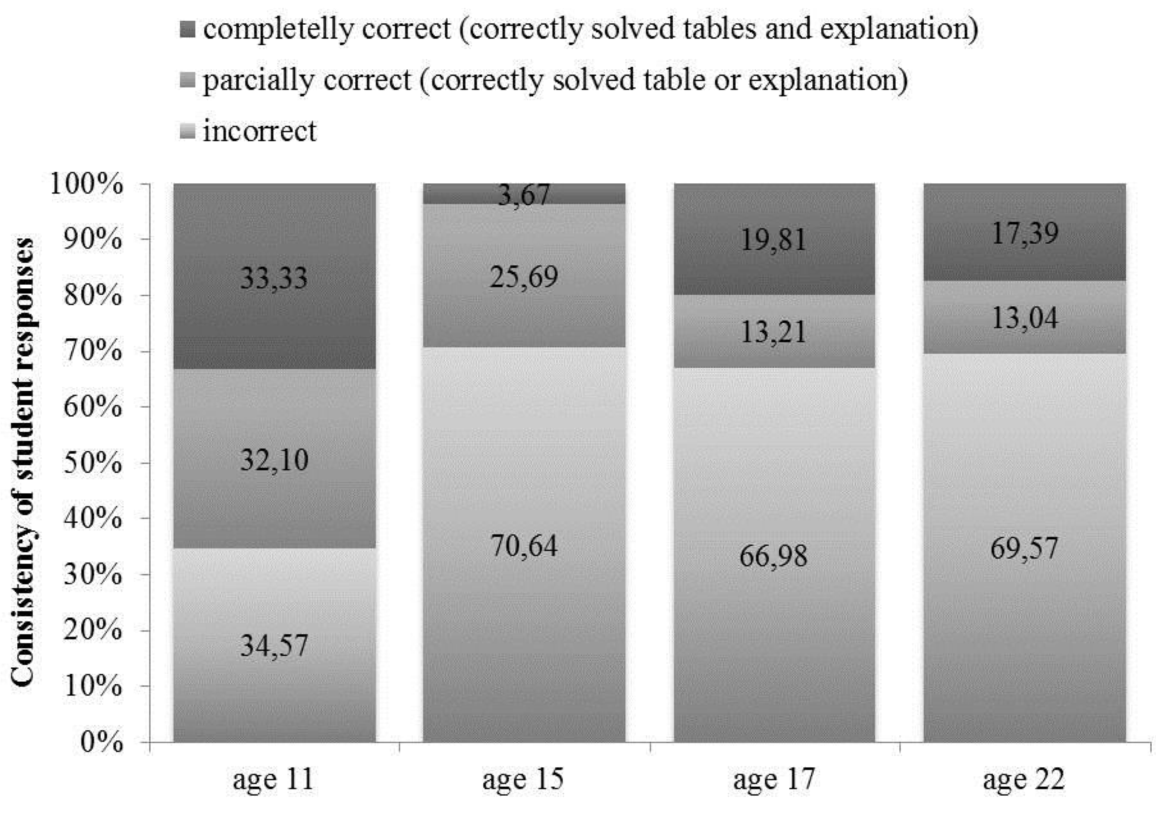


Figure 3. Consistency of student responses.

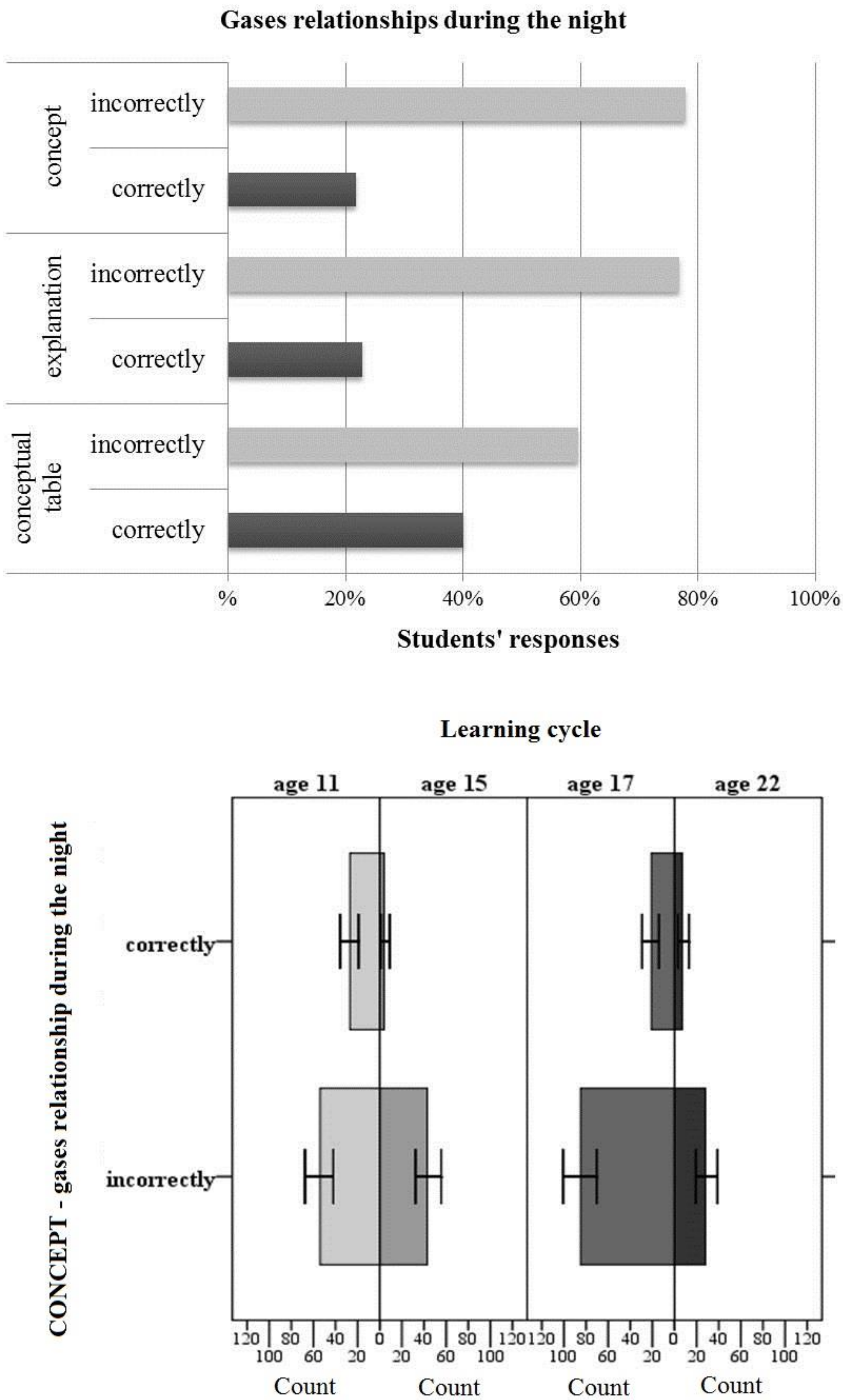
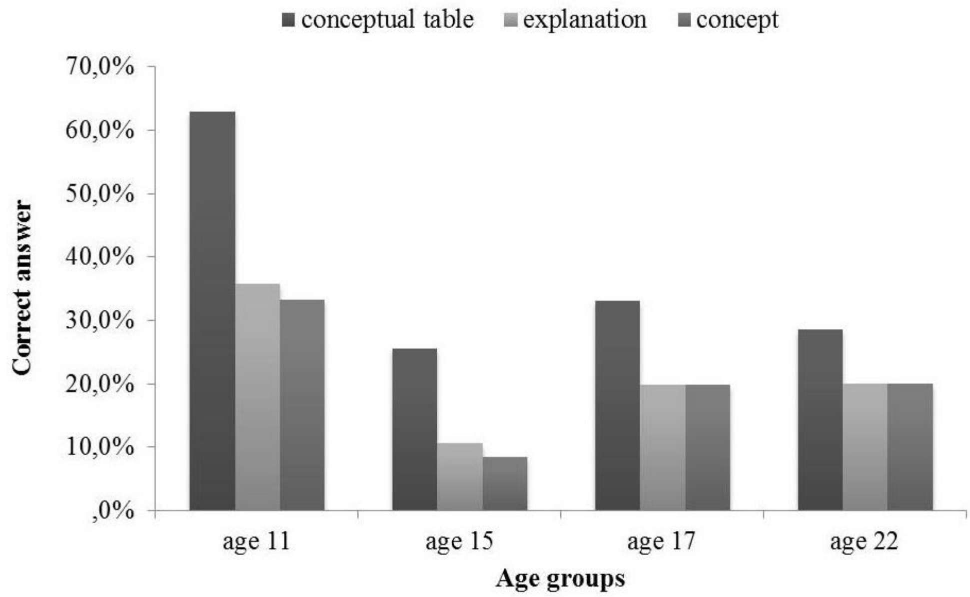


Figure 4. Conceptual understanding based on both parts of the question.



CONCEPTUAL TABLE			
Mann-Whitney U sig. *Rosenthal effect size r*	age 15 (N=47)	age 17 (N=106)	age 22 (N=35)
age 11 (N=81)	< 0,001 *-0,032*	< 0,001 *-0,022*	< 0,001 *-0,029*
age 15 (N=47)		ns *-0,006*	ns *-0,004*
age 17 (N=106)			ns *-0,003*

EXPLANATION			
Mann-Whitney U sig. *Rosenthal effect size r*	age 15 (N=47)	age 17 (N=106)	age 22 (N=35)
age 11 (N=81)	< 0,005 *-0,024*	< 0,05 *-0,013*	ns *-0,014*
age 15 (N=47)		ns *-0,009*	ns *-0,014*
age 17 (N=106)			ns *-0,000*

CONCEPT			
Mann-Whitney U sig. *Rosenthal effect size r*	age 15 (N=47)	age 17 (N=106)	age 22 (N=35)
age 11 (N=81)	< 0,005 *-0,025*	< 0,05 *-0,011*	ns *-0,012*
age 15 (N=47)		ns *-0,011*	ns *-0,018*
age 17 (N=106)			ns *-0,000*

Figure 5. Students' conceptual understanding of the plant's impact to gas ratio during the night.

To identify the answer structure, syntax and diversity used in the students' explanations, we carried out a detailed code-based analysis of the students' answers (Figure 6). Most explanations were lacking a biological sense or they offered definitions of biological terms, but were mismatched and interpreted/linked wrongly. The members of all age groups equally often offered the photosynthesis definition, but without linking it with the posed question and applying it to a specific case, respectively. In comparison to other age groups, students aged 15 most often offered misinterpretations such as *"CO_2 is consumed in respiration"* or *"CO_2 is converted into O_2"*. In general, all groups of students equally often gave incomplete interpretations of photosynthesis focusing only on one aspect of the process (e.g., breathing or absence of light). The responses of older students also encounter idea: *"Calvin cycle (or reactions in the dark) releases oxygen; it happens at night"*. The explanations of university students were not significantly different from the explanations of high school students, although they used more complex terminology (Figure 6).

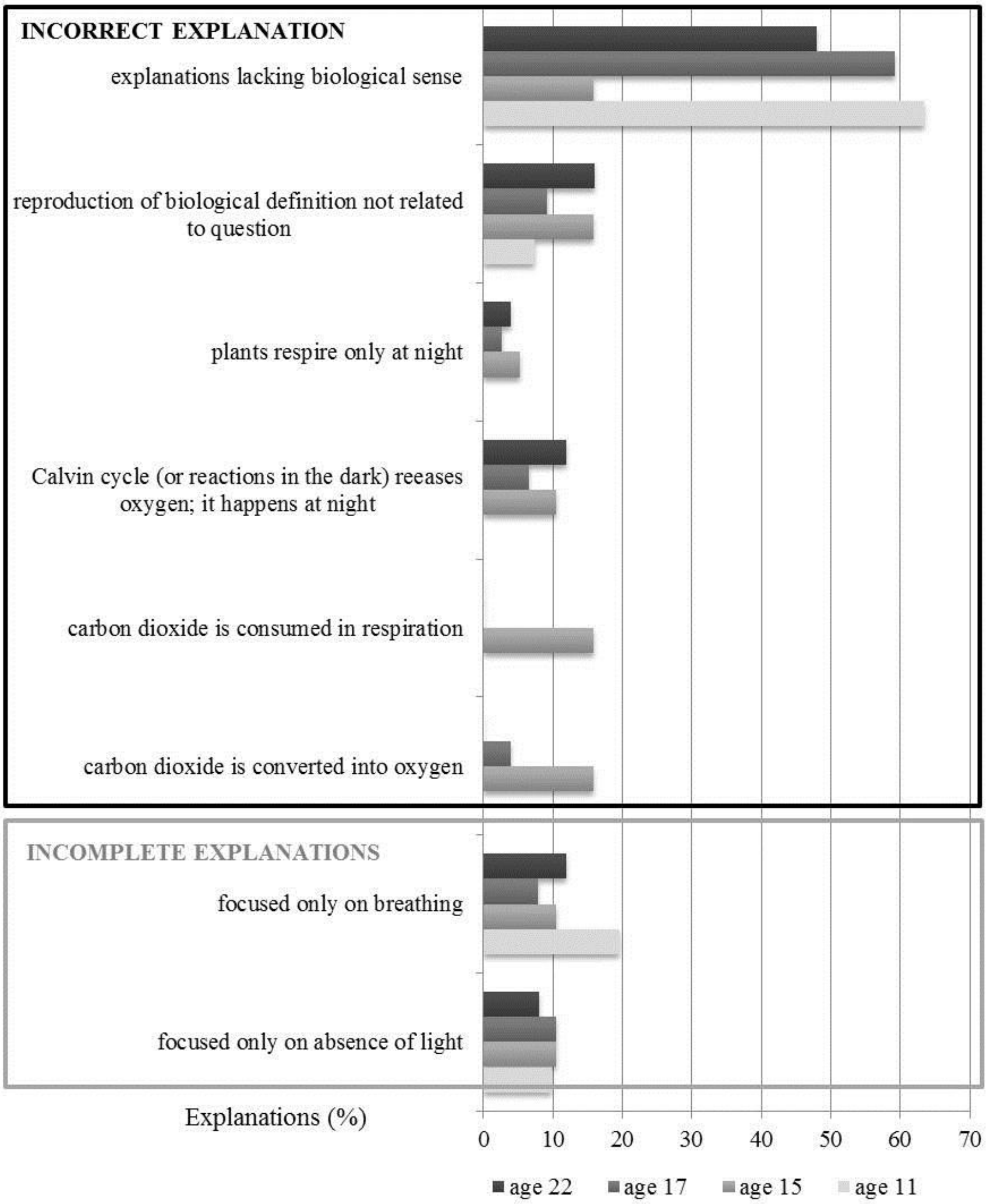


Figure 6. Analysis of incomplete and incorrect explanations.

DISCUSSION AND CONCLUSIONS

From the earliest learning stages, students often keep the misconception that plants *photosynthesize during the day* and *respire at night*. The learning cycle at the students' age of 11 is focused on distinction between the plant respiration and assimilation of CO_2, which likely explains their better performance. Since the older students demonstrate the same misconception again, success at age 11 can be explained as only reproductive knowledge.

At the age of 15, students are taught more details about photosynthesis, but it likely confuses the students and causes the misconception that the secondary reactions of photosynthesis occur at night. Moreover, as the students state that the Calvin cycle produces oxygen (at night), it could be suggested that they mix up the terms and reactions of Calvin cycle and cellular respiration (which was taught previously). This misconception is likely kept among older students.

We suggest that the observed results and student misconceptions are due to the extensive content of the Croatian textbooks and the prevailingly passive teaching modes, in which students are not actively involved in teaching-learning nodes and are not encouraged to think (Banilower et al., 2008). Another important effect is most likely the short time invested into the comprehension of complex concepts as well as learning without students' reflections (Koba & Tweed, 2009).

At the age of 17, the details on Calvin cycle, including names of participating enzymes and coenzymes, are taught. However, to students these processes still remain abstract and distant from their experiences (Russell et al., 2004). By focusing attention on numerous novel names and data, they probably lose sight of the "big picture".

After all, a question of curricular efficacy arises when it appears that students after so much learning are not able to adopt and apply the basic concepts? In this respect, teachers should modify their teaching approach: identify possible misconceptions (Näs, 2010), apply experiential learning and provide students enough time to build their own and complete/organized concept system. In that sense, it would be efficient to create concept maps and problem solving tasks (Köse, 2008).

The results of the present analysis indicate significant problems in understanding the concepts of photosynthesis, which should be an important sign to teachers, and particularly to curriculum and textbook authors to determine facts and details really necessary to understand the process of photosynthesis.

REFERENCES

Banilower, E., Cohen, K., Pasley, J., & Weiss. I. (2008). *Effective science instruction: What does research tell us?* Portsmouth, NH: RMC Research Corporation, Centre on Instruction.

Canal, P. (1999). Photosynthesis and 'inverse respiration' in plants: an inevitable misconception? *International Journal of Science Education*, *21*, 363–371.

Garašić, D., Radanović, I., & Lukša, Ž. (2012). *Usvojenost makrokoncepata biologije tijekom učenja u osnovnoj školi i gimnaziji*. Zagreb, HR: Monografija Akademije odgojnih znanosti RH.

Koba, S., & Tweed A. (2009). *Hard - to - teach biology concepts; a framework to deepen student understanding.* Arlington, VA: National Science Teachers Association.

Köse, S. (2008). Diagnosing student misconceptions: Using drawings as a research method. *World Applied Sciences Journal*, *3*(2), 283–293.

Magntorn, O. (2007). *Reading nature. Developing ecological literacy through teaching.* The Swedish National Graduate School in Science and Technology Education. Linköping University.

Näs, H. (2010). *Teaching photosynthesis in a compulsory school context - students' reasoning, understanding and interactions*. Doctoral thesis. Umeå University. Umeå National Research Council Investigating the Influence of the National Science Education Standards. Washington, DC: National Academies Press.

Özay, E. & Öztaş, H. (2003). Secondary students' interpretations of photosynthesis and plant nutrition. *Journal of Biological Education*, 37, 68-70.

Russell, A. W., Netherwood, G.M.A., & Robinson, S.A. (2004). *Photosynthesis In Silico. Overcoming the Challenges of Photosynthesis Education Using a Multimedia CD-ROM.* Bioscience Education E-journal, volume 3, available at http://bio.ltsn.ac.uk/journal/vol3/beej-3-8.htm (accessed 25 March 2013)