PART 5: NATURE OF SCIENCE, HISTORY, PHILOSOPHY, SOCIOLOGY OF SCIENCE

Co-editors: Laurence Maurines and Andreas Redfors

The implications of nature of science, its history, philosophy, sociology and epistemology, for science education. The significance of models and modelling for science education as reflected in the particular importance attached to the use of metaphors, analogy, visualization, simulations and animations in science.

This part corresponds to strand 5. It contains 24 papers.
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INTRODUCTION

These last twenty years, curricula at all three cycles of education have undergone many reforms, both in Europe and elsewhere. The aim is to give all students the opportunity to encompass the scientific and cultural background that allows them to become responsible citizens, capable of understanding and taking action in a world where science and technology occupy a predominant role. Science programs focus on scientific problem solving with methods and skills to be acquired and attitudes such as critical thinking to be internalized. Emphasis is put on knowledge about the nature of science and scientific activity. In particular, students and future citizens are expected to be able to distinguish between what is science and what is not, and develop skills to be able to utilize scientific theories as parts or bases for discussion and explanations of science and technological phenomena met in current and future everyday life. However, these epistemological issues of scientific education, more or less addressed in different countries and curricula, are often implicit in terms of pedagogical goals, content and activities.

The epistemological dimension of science teaching has attracted the attention of many science educators and researchers. Inquiry-based teaching and history and philosophy of science are proposed as strategies to enhance students’ views of the nature of science and scientific activity. The field of research presented in this strand explores numerous questions: teaching contents and objectives, students’ and teachers’ views, e.g. in relation to religious views, the role of Philosophy of Science, teachers’ practices such as inquiry-based teaching and role-playing, the significance of models and modelling, strategies to enhance students’ and student teachers’ and teachers’ views of the nature of science, and research-based implementations of innovative pedagogical units which explicitly or implicitly address the NoS question.

We invite you to enjoy the following articles, The Strand Editors
THE CONCEPT OF ANALOGUE MODELLING IN GEOLOGY: AN APPROACH TO MOUNTAIN BUILDING

Edite Bolacha¹, Helena Moita de Deus¹ and Paulo Emanuel Fonseca¹²
¹LabGEXP- Laboratório de Geologia Experimental, Centro de Geologia da Faculdade de Ciências da Universidade de Lisboa, Portugal.
²Departamento de Geologia da Faculdade de Ciências da Universidade de Lisboa, Portugal.

Abstract: Analogue modelling has been used, in geological research, since the XIX century. Today, both in scientific investigation and in teaching, it is viewed as an indispensable tool in the reconstruction of ongoing geological phenomena, as well as it is fundamental to infer geological processes that happened throughout Earth’s History.

Considering that analogue modelling can be used as a teaching strategy, when teaching Geology or any other experimental science, it is relevant to define the concept and to reveal its applications and vantages.

As it reconstructs and explains past phenomena through the establishment of cause-effect relations with today’s analogue phenomena, analogue modelling became an important methodology in the construction of geological knowledge. This line of thinking has been used, for long, by geologists and, when transferred to the classroom, it can deepen the understanding of Geology. In order to do so, teachers need to plan and test carefully these activities, which usually include other teaching strategies simultaneously. These activities promote student’s involvement in their learning, therefore developing multiple skills.

The genesis of a mountain range has always been a central issue for Mankind, in general, and for Geologists, in particular. Therefore, as Geology Theories about this matter have evolved, so have evolved the modelling techniques and, consequently, the teachers should adjust these methodologies in the classroom.

Here is presented a new didactic analogue model of (segments of) mountain building adapted from updated scientific models. It was applied in a Geology class with 12th grade students. This preliminary study showed that analogue modelling helped them to reconstruct their mental models about a contextualized episode of regional Geology.

Keywords: Analogue Modelling, Teaching of Geology, Experimental work, History and Epistemology of Geology, Mountain building.

INTRODUCTION

Materials and equipments used in analogue modelling have been evolving since the XIX century (Oreskes, 2007; Schellart, 2002; Ranalli, 2001). Today this methodology is commonly used in scientific research to simulate geological processes that occurred in well determined time and space units. This is done using dynamic models, built to scale, which allow to the manipulation of several variables, selected according to the object of the investigation (e.g. Malavielle, 2010).

Despite its limitations (Deus et al., 2011), analogue modelling can easily be applied to the teaching of Geology (either formally or non-formally), because planning a didactic activity requires a certain measure of simplification of the geological phenomena, leading to less variables to control. Visualizing the evolution of the studied geological processes empowers this teaching strategy, making it easy to transfer the studied phenomena to the reality, past or present (e.g. CNRS-GeoManips). In all cases, the teacher should be careful regarding the way knowledge is presented, making sure that the students fully understand the limitations of the
model at hand, especially by discussing the complexity of the phenomenon investigated. This more systemic view of geological phenomena is attainable if its analogue modelling includes a solid scientific and epistemological approach.

GENESIS OF ANALOGUE MODELLING

James Hall de Dunglass, the founder of Experimental Geology, first performed analogue modelling in the XVIII century. Observations made in the field by Hall, James Hutton and John Playfair, were the basis for modelling experiments. Likewise, today investigators collect data on the field (figure 1) to create accurate geological modelling (Newcomb, 2009).

Fig.1. In Geology data is collected in the field to support Theories and Models.

James Hall was influenced by Hutton’s theory which considered that rocks were formed by the solidification of magma and its compression, at great depths. So, Hall designed a series of experiments to test this theory, despite the fact that many other investigators (including Hutton) opposed, arguing that the experiments didn’t respect real time and space units in which those phenomena had occurred. Furthermore, they stated that the cause-effect relations established by those experiments were not analogue to the natural phenomena (Oreskes, 2007; Newcomb, 2009). Throughout time, this argument was used by the skeptics of experimental Geology, particularly concerning the construction of models (to scale) of mountains and crust deformation, developed during the XIX century (Oreskes, 2007; Ranalli, 2001). This scientific controversy should be discussed when teaching these phenomena (formally or non-formally), conveying to students a more human view of the scientific activity.

The genesis of a mountain range was a key subject among geologists of the XIX century; so, Hall searched for a way to model that phenomenon. Eventually, he was able to find a mechanism to do it, and this became a prototype to future modelling activities on the XIX and XX centuries. After carefully observing geological structures in the field (mainly folds), Hall used simple materials (first, tissues, and later, clay) to simulate the dynamics that originate a folded mountain range (Newcomb, 2009). He applied geometrical similarities (similar geometry of the structures), kinematics and dynamics – from a qualitative point of view (Ranalli, 2001). The calculations of the model’s dimensions were based on the figurative geometry, kinematics and dynamic that characterize the natural phenomenon modelled (e.g. Hubbert, 1937). This became a very important approach to modelling because the respect for scale enhances the analytical power of the model created, narrowing the gap between the
modelled phenomenon and the natural one. This way the experiment is more reliable and easier to reproduce, therefore closer to what a scientific experiment should be.

**IMPORTANCE OF ANALOGUE MODELLING**

Taking into consideration all the above as well as the current situation of analogue modelling it is admissible that this is an important tool in the construction of geological knowledge. Then, analogue modelling should be included in the teaching of experimental sciences (Gilbert, 2004), along with other kinds of models, for it promotes the comprehension of natural processes’ dynamics and their variables. So, it constitutes good opportunities to enforce the use of experimental teaching approaches (Deus et al., 2011). Moreover, analogue modelling is a dynamic way to simulate natural phenomena, simplifying them and allowing for a deeper understanding. This might require some degree of abstraction, especially if the studied phenomenon establishes an intricate net of relations with other natural phenomena. Recent investigation shows that this can be a challenge if the curriculum presents scientific phenomena in an isolated fashion, with little or no intradisciplinarity (Raia, 2008).

Simulating geological phenomena, which occur in 4 dimensions (3 dimensions of the space plus the time dimension), to scale, allows to a variety of multidisciplinary applications, involving several subjects, both scientific and artistic (Deus et al., 2011). Visualizing scientific processes in 4 dimensions contributes to a better understanding of deep time, which is a difficult, yet very important, concept when educating towards sustainability, putting mankind in a relative position in the timeline of Earth’s History. The visualization of phenomena in space’s 3 dimensions can develop visual skills like: i) observe a 3D image object of a 2D image; ii) mentally rotate an object; iii) imagine sections of an object that has been cut (Gilbert, 2004). All these skills are very important, not only to study Geology, but also when studying engineering or arts. In short, we can say that analogue modelling plays an important role in Science Teaching because it merges several methodologies used in Science, some of which appear in figure 2.

![Diagram](image_url)

**Fig. 2.** Examples of methodologies used in Science which are also used in analogue modelling.

Epistemologically, analogue models are a simplified version of updated scientific models, so that they aren’t reduced to historical representations of outdated theories or explanations (Gilbert, 2004). When using analogue modelling to present an episode of Geology’s History, it should be clearly stated, because it can play an important role in teaching the evolution of geological thinking, as well as to teach current scientific concepts.
MOUNTAIN BUILDING: AN HISTORICAL AS WELL AS AN ACTUAL EXAMPLE

Before Plate Tectonics (1960-1970), many theories came forth to explain the genesis of mountains: from the contractionists (XIX century) to the Theory of the Geosyncline (XX century) (Mattauer, 1980; Oldroyd, 1996; Allegre, 1999). In all these cases, horizontal forces are responsible for the formation of the mountains. What vary, in different theories, are the different sources of those forces (Oreskes, 2007; Oldroyd, 1996).

Hubbert’s model (fig. 3) is an example of how historical models can be adapted to current theory. King Hubbert used his sandbox, in 1951, to show some geologic structures and its physical relationships, as well as their causes. Supported by the Theory of Plate Tectonics the same experiment could explain, for example, the relation between the constancy of the Earth’s perimeter and the compressive and extensive geological processes.

Fig.3. An episode of Non Formal Education in a Science Centre (Centro Ciencia Viva of Estremoz, University of Evora) with a replica of Hubbert’s experiment.

Nowadays, the permanent search for new materials and equipments has led geologists and Geology teachers to the construction of better models. These have been improved by the use of materials with properties that are more analogue to the ones present in natural processes. Therefore, today’s teaching models are closer to modern scientific theories.

According to Plate Tectonics, a mountain range develops mainly in a zone where plates converge. To simulate an oceanic plate and a continental border converging (leading to the genesis of a mountain range like Andes), many appropriate analogue models were built and explored, since the 80s of the XX century, by several groups of scientists (Davis et al., 1983; Malavieille, 2010; Gravelleau & Dominguez, 2008). These are very different from the traditional sandboxes, similar to those used by the pioneers of analogue modelling (e.g. Hall, Cadell, Favre referred by Oreskes, 2007), and many times misused in schools to simulate terminal stages of the collision between the plates that originated the Himalayan Range. Taking this into consideration, it is important to study several mountain ranges, to ensure the multiple possible scenarios, therefore developing complex learning skills and avoiding persistent misconceptions.

An alternative modelling activity, is presented here (fig. 4), simulating the genesis of a mountain range, based on several models developed by other investigators (e.g. Davis et al., 1983; Malavieille, 2010). The model, built at a 1cm:1km scale, and it simulates the genesis of a segment of a mountain range – a accretionary prism, composed by marine sediments, represented by layers of sands with identical internal friction angle and cohesion, therefore
analogue to nature. These layers undergo deformation against a backstop, which is analogue to the marine platform or to an already formed section of the mountain, generated by the force inherent to the subducted plate. This force is simulated by a plastic sheet, underlying multiple layers of sand, which moves towards the backstop. Analogue modelling allows varying several parameters, including the height of the layers of sand, the slope of the backstop or the consequences of erosion (Bolacha et al., 2011). All together, these convey the idea of a dynamic planet, shaped by multiple variables throughout the Eons of geological time.

Fig. 4. Top picture – early stage of analogue modelling segment of a mountain building. Picture below- the final stage of the same model.

This analogue model was used in a Geology class (12th grade portuguese students) to extrapolate and reconstruct an episode of the geological history of Iberia: the genesis of the accretionary prism of South Portuguese Zone (Ribeiro et al., 1979; 2007). Geological maps, texts and images of regional outcrops were used before the analogue modelling activity, in order to help students to construct their mental models (Greca and Moreira, 2000 and references insight) about phenomenon under investigation.

The preliminary results showed that analogue modelling helped the students to reconstruct their mental models about this segment of mountain building along a convergent margin. Before the activity of analogue modelling, most of them had mental models which didn’t include the existence of a subduction zone, i.e., closer to the model of the traditional sandbox. Their first mental models about mountain building were consistent with other identified and described by others researchers (e.g. Sibley, 2005; Arthurs, 2011). Having the power to induce the reconstruction of the first mental models, analogue modelling is proved to be an important didactic tool. It leads to conceptual change about dynamic processes studied and to the deconstruction of wrong ideas many times included in images and texts in various forms (e.g. books, newspapers, and cyberspace).
A more detailed study of this approach in Geology Teaching will be a part of a PhD thesis.

CONCLUSION

Analogue modelling has an important place in Science Teaching because it merges several methodologies characteristic to Science. The use of analogue modelling should be carefully planned taking into consideration the targeted public, so that they can be guided towards the questioning about analogue modelling limitations, namely time, space and the nature of the analogue materials and their rheological behaviour. Furthermore, this teaching strategy should be presented within a theoretical framework, currently accepted by the scientific community, so that it may impart updated knowledge and/or knowledge under construction.

When properly used, analogue modelling can promote conceptual change, leading to a better understanding of present and past geological phenomena.

In future, deeper studies will be conducted in order to confirm the results here presented, that showed that the use of this particular model helped to changed students’ mental models about the relevancy of subduction as an important mechanism underlying mountain building. Therefore, their mental models became closer to actual scientific models about mountain building associated with plate convergence.

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EVALUATING STUDENT GAINS IN THE PROFILES PROJECT*

Claus Bolte¹, Sabine Streller¹
¹Freie Universität Berlin (GERMANY)

Abstract: Intervention projects – such as and especially as large as PROFILES – need to clarify the success of their efforts regarding the projects aims. In the case of PROFILES our intervention and efforts are trying to promote - among other objectives the enhancement of students Scientific Literacy.

More specifically, PROFILES aims to promote student gains and thus, the PROFILES project tries to

- balance the attitudes of students toward science and the science education they receive,
- negotiate the meaning and relevance of science education so that science lessons will become more meaningful in eyes of the participating students,
- enhance students intrinsic motivation to learn science and
- foster their abilities and skills especially in the field of learning approaches to science inquiry making justified decisions regarding socio-science and science related issues.

This publication will introduce a theoretically and empirically sound model of teaching and learning science as well as questionnaires and instruments for the investigation of the aims mentioned above. Furthermore we will present and discuss results from different intervention studies obtained by means of the different questionnaires and instruments (mentioned above). The results will be used as examples to offer insights into the potential of the questionnaires and pre-post-intervention-and-control-group design approach. In addition first results from the PROFILES Working Group of the Freie Universität Berlin will be presented.

Keywords: IBSE, student gains, Motivational Learning Environment (MoLE) Model, scientific competencies and life skills, project evaluation and questionnaires.

1 INTRODUCTION: PURPOSE OF PROFILES

PROFILES is the acronym for: Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science. As mentioned in the PROFILES Project symposium at ESERA 2011 (Bolte et al., accepted; see this proceedings), PROFILES is aiming to implement existing IBSE-focused science teaching materials by means of (long-term) teacher training courses to support teachers’ continuous professional development (CPD). The PROFILES consortium members are convinced that the PROFILES CPD programme will convince teachers to take ownership regarding the implementation of evidence based best practice learning environments in order to foster science education and scientific literacy among their students (PROFILES 2010).

Intervention projects such as – and especially such as large as – PROFILES need to clarify the success of their efforts regarding the projects aims. In the case of PROFILES our intervention
and efforts are trying to promote - among other objectives (e.g. the increase of teacher ownership) - the enhancement of students’ scientific literacy (Gräber & Bolte 1997).

To be more specific, PROFILES aims to promote student gains and by trying to…

(a) balance the attitudes of students toward science and the science education they receive,
(b) negotiate the meaning and relevance of science education so that science lessons will become more meaningful in eyes of the participating students,
(c) enhance students intrinsic motivation to learn science and
(d) foster students abilities, skills and competencies especially in the field of learning approaches to science inquiry making justified decisions regarding everyday life, socio-scientific-science and science related issues.

2 FRAMEWORK AND CONCEPTION OF THE PROFILES PROJECT EVALUATION CONCERNING STUDENT GAINS

“Europe needs more scientists“ is the title of the high level group report chaired by M. Rocard and published by the European Commission (2004). But, young adults won’t apply for a job in the sciences,

- if their experiences in science are not meaningful,
- if science instruction is less motivating,
- if scientific concepts are considered as irrelevant and
- if persons working in the sciences associate with a negative stereotype (Bertels & Bolte, 2009; 2010; see figure 1).

Figure 1: Model of selected variables which effect students’ choice of a career in the sciences (according to Bertels & Bolte 2010)

With these aspects in mind, the PROFILES project places a special emphasis on identifying student gains in the affective component – esp. in the (intrinsic) motivational part of science learning and scientific literacy. Above and beyond - but not exclusive - PROFILES also pay attention to specific scientific competencies (e.g. scientific inquiry skills and/or skills of justified and/or informed decision making).

Analysing the outcomes of the PROFILES intervention, linked to the teachers continuous professional development and the promotion of the PROFILES teachers to take ownership for
more innovative practices in their science classes, the question of the impact of the project on students is the core part of the PROFILES Work package 7 (see Bolte et al. in this proceedings and/or PROFILES 2010). But evaluating the effectiveness of the PROFILES interventions from a student perspective does not mean that cognitive components are analysed only by means of conventional knowledge tests or that the focus of the evaluation should be on those objectives as they are often described in national education standards. Attention is also paid to evaluate students’ motivational gains and the development of their affective skills as well as the students’ attitudes related to science, science education and other fields of the sciences (such as (not) choosing a vocational career in a field of the sciences; European Commission, 2004).

Therefore, the PROFILES consortium hypotheses that if science teaching is experienced to be meaningful and profitable, in the students’ opinions, (see variable “relevance” in fig. 2), science education and learning science will be strengthened with regards to cognition and contents (see variable “outcomes” in fig. 2) as well as concerning the affective domain of learning science (see variable “satisfaction” in fig. 2). A mixture of cognitive and affective variables which PROFILES will take into consideration are variables such as interest and attitudes towards science, science learning, the image of science and/or of people working in the sciences (also attributed to the variable “outcomes” in the model of fig. 2).

However, the PROFILES consortium agree to the opinion of the European Commission that effective teaching is recognised as a great contribution to a “generally increased knowledge in the sciences for the young generation” (FP7-SiS-call, 2009, p. 22). Therefore, science education – as it is promoted by the PROFILES project – can be taken to be successful if the evaluation demonstrates that the “falling interest in key science topics can be removed and if the lessons foster stimulating intrinsic motivation” (FP7-SiS-call, 2009, p. 20). High intrinsic motivation in learning science (Streller, 2009; Bolte, 2006), enlightened attitudes towards the sciences (Streller, 2009) and a reflective self-to-prototype-matching concerning the prototype regarding employees in the sciences and one’s own self-image (Bolte & Bertels, 2010) are seen as reliable predictors to assess whether an “increase in the numbers of young people in Europe taking up scientific careers” (FP7-SiS-call, 2009, p. 22) is likely (Bertels & Bolte, 2009; 2010).

The theoretical framework of the PROFILES student gains evaluation is based on a model of science instruction and the effects of important variables of innovative and motivational learning environments on students’ outcome (Bolte, 2006; see figure 2). The core part of this model is related to motivation and interest theories as well as to recommendations from learning environment research (Fraser, 1989; Hoffmann et al., 1998; Gräber, 1998; Deci & Ryan, 2002; Bolte, 2006; Streller, 2009).

The so called MoLE-model (MoLE is the acronym for: Motivational Learning Environment) has been tested by means of LISREL Multi Level Structure Analyses (Koeller & Bolte, 1994). These analyses show that the model is theoretically sound and empirically valid. Furthermore, other analyses reveal that the variables of the MoLE-model and the scales of the questionnaire instrument which is based on this model are highly reliable and also valid regarding the construct validity of our theoretical assumption (Bolte, 2006).

In 2009 Bolte extended his MoLE-model to clarify the questions such as:
(a) ‘What is “relevant” from a students’ perspective in science lessons?’ and
(b) ‘How can the variable “outcome” be explained in more detail?’

To analyse the question concerning the variable “relevance” Bertels and Bolte (2009) take the “Theory of Developmental Task” developed by Havighurst (1972) as a basis. This theory was adapted and further and elaborated by Meyer (2006) and Schenk (2005) within their theory of
the “learners’ experiences in education and educational development”. Hence, in order to offer more information about the (potential) outcomes, we differentiated this outcome-variable regarding the evaluation of

- “balanced attitudes” (such as the “self-to-prototype-matching” (Hannover & Kessels, 2004) and the science related self-concept of abilities (Hannover, 1998; Bertels & Bolte, 2009; 2010)), as well as the analyses of
- “students competencies” (such as “students’ inquiry qualification” (Erb & Bolte, 2011) and students competencies in making informed and reflective socio-scientific and science related decisions (Bolte, Kirschenmann & Streller, 2009)).

All the mentioned scale have been tested in past studies, and the findings from these empirically based analyses certify all scales (variables) a high level of objectivity and high values of reliability (Cronbach’s alpha; see Bertels & Bolte, 2010; Erb & Bolte, 2011; Bolte, Kirschenmann & Streller, 2009).

Figure 2: Extended Version of the Motivational Learning Environment Model (according to Bolte 2006)

METHODS

The questionnaires and instruments developed and tested by the leader of the PROFILES Work package 7 and his staff members have been adapted for the PROFILES project to analyze and evaluate the effects of the PROFILES intervention; for example:

- the Motivational Learning Environment Instrument (MoLE; Streller 2009; Bolte 2006);
- the Self-to-Prototype-matching questionnaire (StoP; Bertels & Bolte, 2010);
- a questionnaire assessing the support offered to students dealing with selected developmental tasks of young adults (e.g. occupational orientations, self-orientation, individual reflective value system; Bertels & Bolte, 2010),
- the Inquiry Qualification Questionnaire for the analyses of scientific inquiry skills (IQ²; Erb & Bolte, 2011), and/or
• the Questionnaire to analyze competencies in the area of making informed and reflective socio-scientific and science related decisions (Bolte, Kirschenmann & Streller, 2009).

The PROFILES project evaluation is designed as pre-post-intervention-and-control-group study. Before the start of the long-term professional development intervention data will be collected from the participating teachers’ classes (pre-test; intervention-group) and from classes of teachers who don’t participate in the PROFILES teachers continuous professional development programme (control-group). At the end of a school term, both groups will be re-tested with the same instruments again (post-test; in the intervention and the control-group classes).

RESULTS

Results from different intervention studies obtained by means of the different questionnaires and instruments mentioned above are used as examples to offer insights into the potential of the questionnaires and pre-post-intervention-and-control-group design approach. The results and findings from our research can be summarized as follow:

The analyses of our MoLE investigations and especially the comparison of the so called “Wish-to Reality-Differences” points to some (important) reasons why many students end their physics and chemistry classes at the earliest possible grade and why they might not choose a vocational career in the sciences; for example:

- teachers of chemistry and physics often teach topics which are not relevant to students with respect to their everyday life and/or to socio-scientific issues,
- female students assess the learning environment in chemistry classes less favorably than male students do,
- teachers have problems in anticipating their students’ learning environment assessment and need help for the evaluation of the learning climate in their classes,
- teachers are not easily inclined to change the subjects of their instruction to topics of increased relevance although their own estimation would support this.

Comparing the self-images and prototypes of German students and of trainees in the vocational field of the sciences we find differences between the self- and the prototype assessments in both groups, but the difference between self-image and prototype of the trainees is much smaller than the differences analyzed in the group of students. All in all, the prototype - the students have - is rather negative, and their self-image and prototype do not match at all. In other words, the negative prototypes students have might actually be one important factor that influences their choice of career.

CONCLUSIONS AND IMPLICATIONS

The use of the instruments we tested and the design of the PROFILES project evaluation we tried out in the past make analyses possible which clarifies the effect(s) of intervention programs, such as the PROFILES project, on student gains. Furthermore, past studies by means of the introduced questionnaires and the chosen evaluation design show that “various pre-conditions and cultural differences” (FP7-SiS-call, 2009, p. 20) of students can be taken into consideration. Beside this, by means of the here recommended evaluation approach a “differentiating [between] girls’ and boys’ interest” (FP7-SiS-call, 2009, p. 21) and the specific variables of students’ learning outcome becomes possible, reliable and valid.
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**Acknowledgements**

* The PROFILES Consortium consists of: Freie Universität Berlin (Coordinator, Germany); University of Tartu (Estonia); Weizmann Institute of Science (Israel); Universität Klagenfurt (Austria); Cyprus University of Technology (Cyprus); Masaryk University Brno (Czech Republic); University of Eastern Finland (Finland); University College Cork (Ireland); Universita Politecnica delle Marche (Italy); University of Latvia (Latvia); Utrecht University (Netherlands); University of Maria Curie-Sklodowska (Poland); University of Porto (Portugal); Valahia University Targoviste (Romania); University of Ljubljana (Slovenia); University of Vallalodid (Spain); University of Applied Sciences Northwestern Switzerland (Switzerland); Dokuz Eylul University (Turkey); University of Dundee (UK); University of Bremen (Germany); International Council of Associations for Science Education (ICASE, UK).

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PROFILES* – PROFESSIONAL REFLECTION-ORIENTED FOCUS ON INQUIRY-BASED LEARNING AND EDUCATION THROUGH SCIENCE

Claus Bolte¹, Sabine Streller¹, Jack Holbrook², Miia Rannikmae³, Rachel Mamlok Naaman⁴, Avi Hofstein⁴, Franz Rauch⁵

¹Freie Universität Berlin (GERMANY)
²International Council of Associations for Science Education (ICASE: UNITED KINGDOM)
³University of Tartu (ESTONIA)
⁴Weizmann Institute of Science (ISRAEL)
⁵Universität Klagenfurt (AUSTRIA)

Abstract: PROFILES (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science) promotes Inquiry-Based Science Education (IBSE) by supporting science teachers to develop more effective ways to teach students, aided by science education actors (stakeholders). The project is based on “teacher partnerships” aiming to implement existing, exemplary, context-led, IBSE-focused, science teaching materials. Long-term teacher training courses, based on challenges of implementing student relevance is set to improve skills in developing creative, scientific problem-solving and socio-scientific related learning environments. A crucial aim is the strong dissemination of evaluated approaches, reactions from different actors (stakeholders) and insights of the PROFILES Project, making use of the Internet, the PROFILES Newsletter and other media.

Keywords: IBSE, continuous professional development (CPD), stakeholder networking, best practice, scientific competencies, life skills, 21st century science, evaluation.

INTRODUCTION: PROFILES BACKGROUND AND PURPOSE

A student motivational, socio-scientific approach to science teaching is promoted by PROFILES currently one of several European FP7 funded projects in the field of “Science in Society” (PROFILES Consortium, 2010; Bolte, et al. 2012; Bolte & the PROFILES Consortium Members, in progress). The PROFILES Consortium, consists of 21 partners from 19 different countries (status quo: May 2011), is promoting IBSE through raising the self-efficacy of science teachers to take ownership of more student-relevant ways of teaching, supported by stakeholders views. The project is grounded on ‘teacher partnerships’ implementing existing, exemplary, context-led, IBSE-focussed, science teaching materials, guided by long-term teacher training, reflecting on challenges identified by participating teachers to raising their skills in developing creative, scientific problem-solving and socio-scientific related learning environments; learning environments which embrace students’ intrinsic motivation to learn science and enhance competencies in undertaking scientific inquiry and socio-scientific decision-making. Measures of success are through determining (a) the self-efficacy of science teachers in the PROFILES approach and (b) the attitudinal gains by students towards science and their science education.
The dissemination of PROFILES approaches, reactions from a range of stakeholders and insights from associated research and evaluation form a further key project target. The intended outcome of PROFILES is science education become more meaningful to students, more strongly related to 21st century science, more associated with generic education and especially promoting and enhancing IBSE in school science. In short, the ultimate PROFILES target is to raise teacher’s continuous professional development (CPD) and students’ scientific literacy.

FRAMEWORK AND CONCEPTION OF THE PROFILES PROJECT

The PROFILES project aims at ensuring the improvement of science education by offering innovative scientific learning opportunities for pre- and in-service teachers, teacher educators, as well as students within school and in non-formal education centres. The PROFILES consortium members are confident to reach this aim by:

- **Establishing close cooperation and networking of the consortium with stakeholders** (see table on WP2 ‘Support and Co-operation’ and WP3 ‘Stakeholder Views’) which provides strong teacher guidance to assist in removing possible obstacles and to build up confidence that the disseminated materials, conceptions and programmes are being enacted, bearing in mind stakeholder views and evaluated, in terms of approval, by stakeholders.

- **Providing teacher training and innovative inquiry-based teaching approaches** to introduce methods of, and teaching modules for, learning and teaching IBSE inspired science, which feature specifically relevance-identified modules (see WP4 ‘Learning Environments’), and training programmes linked to classroom intervention support. The introduction of PROFILES ideas into pre-service student teacher programmes, by enhancing science educator awareness and interest, is also intended (see WP5 ‘Teacher Training’).

- **Developing strong(er) teacher professionalization and enhancing teacher self-efficacy** through building on an intervention, guiding teacher reflective processes and teacher initiating use-inspired research accomplishments. Additionally professionalization is enhanced through teacher ownership (see WP6 ‘Teacher Ownership’) enacted through adaptation of state-of-the-art teaching modules related to cultural pre-conditions and gender factors, as well as reflective portfolios and action research projects.

- **Evaluating the outcomes of the intervention linked training regarding student gains** (see WP7) and the promotion of teachers take ownership of more innovative practices, concerning the students in terms of both attitudes towards the teaching approaches, and their perception of, and interest in science-related learning and careers in the sciences.

- **Disseminating the PROFILES ideas, materials and outcomes** and its potential for greater adoption through establishing teacher networks and interacting with other regional and national networks, as well as networking with other innovative IBSE science teaching projects (see WP8).

The PROFILES educational philosophy is introduced to central stakeholders within the education system of each consortium country via eight inter-dependent work packages (rf. Table 1 and Figure 1). An intended outcome, through continuous professional development (CPD) of science teachers, is to create interactive local, regional, national and Europe-wide
teacher networks which positively influence teachers’ competence and confidence to promote IBSE-related science teaching and hence raise their self-efficacy to teach in an innovative – more student centered, context-led IBSE – manner, as well as in valuing use-inspired research ideas. This will be evaluated by means of systematic, statistically-based methods, as well as with the help of action research activities.

<table>
<thead>
<tr>
<th>Work Package</th>
<th>Short title</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP 1</td>
<td>Management and evaluation</td>
<td>Project management and external evaluation.</td>
</tr>
<tr>
<td>WP 2</td>
<td>Partner co-operation and professional support</td>
<td>Partner professional support to guide PROFILES as per the intended philosophy, goals, outcomes and stakeholder views.</td>
</tr>
<tr>
<td>WP 3</td>
<td>Stakeholder involvement and interaction</td>
<td>Bridging the gap between science education researchers, educators, and local actors (stakeholder network and co-operation).</td>
</tr>
<tr>
<td>WP 4</td>
<td>Learning Environment</td>
<td>Preparing focus of teacher training materials and identification of IBSE related teaching modules plus their modification and enhancement, based on evaluative feedback and involvement of additional teachers in PROFILES.</td>
</tr>
<tr>
<td>WP 5</td>
<td>Teacher Training and Intervention</td>
<td>Planning and Implementation of the (longitudinal) teacher training programme and inter-related teacher interventions.</td>
</tr>
<tr>
<td>WP 6</td>
<td>Teacher Ownership</td>
<td>Building on WP5 and reflecting and evaluating the effectiveness and impact of the (longitudinal) teacher training programme with special emphasis on teacher ownership and reflective practices.</td>
</tr>
<tr>
<td>WP 7</td>
<td>Student Gains</td>
<td>Evaluating the effectiveness and impact of the teacher training programme/intervention and development of teacher ownership by focusing on student outcomes.</td>
</tr>
<tr>
<td>WP 8</td>
<td>Dissemination and Networking</td>
<td>Dissemination at a national, international and worldwide level and establishment of a PROFILES teacher network interrelated to other teacher networks operating at a local, regional, national or Europe-wide scale.</td>
</tr>
</tbody>
</table>

**Table 1. Work packages of the PROFILES Project.**

Within this intended outcome, and by means of a (long term) teacher continuous professional development (linked and supported by stakeholders) a further key target of PROFILES is to convince teachers that the methods they have studied within the PROFILES programme and tried out during the PROFILES classroom interventions in their science classes will, and can, strongly improve the quality of their own science teaching.

Furthermore, teachers - especially those who participate in the PROFILES longitudinal CPD programme – will become convinced of the need for change in conventional practice. The new viewpoints they have learned in the PROFILES teacher meetings they will discuss with their colleagues; especially the need to interact and to seek for further support by networking with other colleagues (e.g. colleagues of other subjects in their schools, or from ‘nearby schools’ etc.). Beside this, the PROFILES Consortium expects that the teachers, participating in the PROFILES programme, will be motivated to disseminate their new experiences and the PROFILES IBSE teaching and learning materials through informal and/or formal teacher forums. This will be encouraged both through activities organized by the Consortium partners (e.g. via the PROFILES websites and dissemination network) and by follow-up training courses and informal teacher meetings after the longitudinal teacher CPD programmes at a regional, national and Europe-wide level.
Figure 1. Interdependencies of the PROFILES Project’s Work packages

A reflective impact component, first guided by the consortium partners, but later by specific teachers (referred to as ‘lead teachers’), is designed to follow-on from the initial training and intervention to raise teachers estimation of responsibility for self-evaluating approaches to analyse students’ enhancement of scientific literacy in the participants’ schools and/or classes of teachers’ special interest groups. These aspects, linked to teachers’ self-efficacy, will motivate PROFILES teachers to evaluate their own professional developments as well as guide other colleagues in investigating the success of their teaching; for example by means of action research methods. Professional attitudes like these, we term “teacher ownership”.

Confidence that the objectives of the PROFILES Project - the effective and sustainable improvement of teaching through the promotion of self efficacy and teacher ownership - will be reached, is strengthened through evaluation, by both formal and summative assessment. Our evaluation will focus on students’ cognitive and affective learning and also on the teaching methods, approaches and materials used within the PROFILES intervention lessons. By means of the PROFILES evaluation it is intended to indicate where improvement is justified and where additional efforts are necessary to improve IBSE to meet stakeholder wishes, as well as teachers and students needs.

From the initiation of the project in December 2010, the PROFILES Consortium emphasises the dissemination of products, experiences and evidence-based outcomes of the project; starting with specific national PROFILES websites in each consortium partner’s language and by encompassing the international PROFILES platform (www.profiles-project.eu). But realising that dissemination by partners alone is insufficient, further efforts are included by the PROFILES Consortium to support teachers and stakeholders in general, to appreciate the project and its developments (e.g. by means of strengthened teacher networks and their networking). Through these efforts and interacting with other teacher networks, links are widened, ideas of IBSE are disseminated and teacher-teacher interaction enhanced across borders (insofar as language aspects permit).
Our first steps in dissemination have been taken by presenting the PROFILES Project and its coordinating and supporting actions at international conferences (e.g. Scientix 2011 in Brussels, ESERA 2011 in Lyon, and GDCP 2011 in Oldenburg). A key future event through which it is possible to interact with the PROFILES project and its consortium members, teachers and stakeholders, will take place in Berlin 2012 from the 24th to 26th September, 2012. Those interested to meet PROFILES and the PROFILES actors are invited to participate in this, the 1st International PROFILES Conference on Stakeholders Views and the Enhancement of Inquiry Based Science Education. For more information, please, visit the PROFILES website: www.profiles-project.eu.

Figure 2. Overview of the countries involved in the PROFILES Project’s Consortium*

* The PROFILES Consortium consists of: Freie Universität Berlin (Coordinator, Germany); University of Tartu (Estonia); Weizmann Institute of Science (Israel); Universität Klagenfurt (Austria); Cyprus University of Technology (Cyprus); Masaryk University Brno (Czech Republic); University of Eastern Finland (Finland); University College Cork (Ireland); Universita Politecnica delle Marche (Italy); University of Latvia (Latvia); Utrecht University (Netherlands); University of Maria Curie-Skłodowska (Poland); University of Porto (Portugal); Valahia University Targoviste (Romania); University of Ljubljana (Slovenia); University of Vallalodid (Spain); University of Applied Sciences Northwestern Switzerland (Switzerland); Dokuz Eylul University (Turkey); University of Dundee (UK); University of Bremen (Germany); International Council of Associations for Science Education (ICASE, UK).
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ASSSESMET OF THE IMPACT OF SCIENCES STUDIES IN UNDERSTANDING THE NATURE OF SCIENCE IN SIX COUNTRIES

Cardoso, Néstor1; Morales, Edna1 & Vázquez, Angel2
1 University of Tolima (Colombia) nrcardoz@ut.edu.co; ednaelianamorales@gmail.com.
2 University of Balearic Islands (Spain) angel.vazquez@uib.es.

Abstract
This study shows the results of the Questionnaire of Opinions on Science, Technology and Society (Spanish acronym, COCTS) applied to students starting and finishing their undergraduate degrees in university careers related to basic science or teaching training in natural sciences in Colombia, Mexico, Argentina, Spain, Portugal and Brazil (Spanish acronym PIEARCTS). The topics evaluated were epistemology, history and internal and external sociology of science (Nature of Science and Technology, NoS&T). Using variational analysis it was stated that the background in science was not a meaningful influence in change of attitude on the NoS&T. Students from Spain and Argentina who had completed studies in science (senior students) had better-informed attitudes than those who just began college (freshman). On the other hand, students from Portugal, Colombia, Mexico and Brazil did not show big differences in attitude.

Keywords: Nature of Science. Science, Technology and Society. Science Education. Conceptions assessment.

The Science, Technology and Society (STS) educational movement advocates for a scientific education with a more humanistic approach, including the social dimension of science and technology in science education, taking into consideration ethical values towards science and technology and a democratic point of view to take informed decisions in public matters.

The inclusion of epistemology, history and sociology of science as part of the meta-theoretical discourse has placed science in another context and under another value. According to internal and external factors, science is considered part of a broader cultural context where scientists are product of the same culture. Stated briefly, it is accepted that there is a social contract among society, science and technology, more or less implied, where each supports and builds up the other. The new contextualization of science has produced recent educational research about teachers and student’s attitudes thus creating ideas about NoS&T more complex but less absolute.

Studies from Manassero and Vázquez (2002) and particularly Liu and Tsai (2008) examine the differences among different groups of science and non-science students attending two public universities. Generally speaking, students did not have sophisticated beliefs about the epistemology of NoS&T, specifically those referred to theory-laden and cultural dependent aspects of science. Students who were acquiring academic background to become science teachers attained the lowest scores among the groups evaluated.
(science, non-science and science education students). The bottom line is that science education should be relevant to the complexity of these epistemological beliefs.

Within this framework and the goals of the PIEARCTS project, a comparison of the attitudes held by freshman and senior students of science in some aspects of NoS&T is presented in order to identify relevant differences between those two groups. It is assumed that students who complete their studies in science (seniors) show more sophisticated beliefs than students who begin college (freshman).

METHOD AND INSTRUMENT

According to the PIEARCTS methodology, the COCTS questionnaire (Forms 1 and 2) was applied according to 30 items related to NoS&T. For the comparative analysis, the attitudinal indexes from two types of students were taken into account, through the mean and standard deviation for each question. The analysis stated that the closest the index value to the positive side (+1) the higher the attitude’s appropriateness and the more informed. While the closest the index value to the negative side (-1) the lower the attitude’s appropriateness, uninformed and naive. To determine significant differences, ANOVA was performed based on the interval p <0.01. The differences weight was established according to its relevance.

SAMPLE
The total of students answering the COTCS questionnaire in six countries were two thousand three hundred twenty four (2324). One thousand one hundred seventy four (1174) answered Form 1. From this sample, six hundred sixty five (665) were freshman students and five hundred nine (509) where senior students. Form 2 was answered by one thousand one hundred fifty (1150). From this sample, six hundred fourteen (614) were freshman and five hundred thirty six (536) were senior students.

RESULTS
Figure 1 shows the overall averages in sentences, categories and items evaluated in the COCTS (Form 1 and 2) questionnaire by identifying the information level of NoS&T for each group of students (freshman and senior) in the six countries reviewed.
Attitudinal averages do not exceed 0.19. This is statistically interpreted as neutral attitudes towards NoS&T. Students who answered Form 1 in COCTS questionnaire revealed better-informed attitudes than those students who answered Form 2. This means that there are less informed attitudes on issues related to the definition of technology\textsuperscript{1}, the role of industry, educational institutions\textsuperscript{2}, social responsibility information, social decisions, gender equity, classification schemes, role of assumptions and epistemological status\textsuperscript{3}.

\textsuperscript{1}For example, students believe that technology is an application of science (Sentence, 10211B). They also think that heavy industry should be moved to underdeveloped countries to save developed countries and future generations of pollution (Sentence, 40161,A).

\textsuperscript{2} On the issue related to educational institutions, students do not consider necessary to study science, because not everyone can understand it. They also believe that science is not really necessary for everyone (Sentence, 20511G).

\textsuperscript{3} On issues related to the epistemological component of the NoS&T, particularly, the classification schemes and epistemological status of science, students consider that the classifications made by scientists, because they have tested over many years of work (Sentence, 90311A). They also think that scientists discover laws, hypotheses and scientific theories (Sentence, 91011A).
The Spanish and Argentine freshman students have the highest rates in both Form 1 and 2. These students have better-informed attitudes than freshman students, as one would expect. On the other hand, freshman and senior students from Spain, Argentina, Portugal and Brazil show similar values in Form 1.

Based on the issues in Form 2, senior students demonstrate less informed attitudes compared to freshman students. This means that the process of education in science does not imply a better understanding of the NoS&T. According to sentences in Forms 1 and 2 and items in Form 2, Mexican students got the most negatives indexes, indicating misinformed attitudes. Regarding the issues on the questionnaire, Argentinean and Mexican students did not show significant or relevant differences, based on variational analysis. (t> 0.3). This means that science and technology courses do not have an impact on the improvement or acquisition of informed beliefs on NoS&T.

Table No. 1 presents the effect size on the issues where the differences between the two groups are significant. Spain has the highest number of significant and relevant differences (9/30). Eight of these are of senior students, among the thirty items assessed.

Table No.1. Significant and relevant differences on items

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>FORM 1</th>
<th>EFFECT SIZE</th>
<th>FORM 2</th>
<th>EFFECT SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>F1_40161 Social responsibility contamination</td>
<td>0.6393</td>
<td>F2_10421 Interdependence quality of life</td>
<td>0.6673</td>
</tr>
<tr>
<td></td>
<td>F1_30111 Interaction STS</td>
<td>0.5206</td>
<td>F2_20511 Educational Institutions</td>
<td>0.6376</td>
</tr>
<tr>
<td></td>
<td>F1_40531 Life welfare</td>
<td>0.3783</td>
<td>F2_60521 Women like men</td>
<td>0.4994</td>
</tr>
<tr>
<td></td>
<td>F1_40221 Moral decisions</td>
<td>0.3621</td>
<td>F2_50111 Union two cultures</td>
<td>0.4251</td>
</tr>
<tr>
<td></td>
<td>F2_40211 Application to daily life</td>
<td>-0.3792</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>F2_90311 Classification schemes</td>
<td>-0.6032</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F2_70211 Scientific decisions</td>
<td>0.3796</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F2_40421 Application to daily life</td>
<td>-0.3138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colombia (Bogotá)</td>
<td>F1_20141 Government politics of a country</td>
<td>-0.6501</td>
<td>F2_90521 True assumptions</td>
<td>-0.3186</td>
</tr>
<tr>
<td>Colombia (Ibagué)</td>
<td>F1_40221 Moral decisions</td>
<td>0.8300</td>
<td>F2_10421 Interdependence quality of life</td>
<td>-0.5036</td>
</tr>
<tr>
<td></td>
<td>F2_20511 Educational Institutions</td>
<td>-0.8782</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F2_40421 Application to daily life</td>
<td>-1.3278</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>F2_70211 Scientific decisions</td>
<td>0.37963</td>
<td>F2_40421 Application to daily life</td>
<td>-0.31389</td>
</tr>
</tbody>
</table>

Only fourteen items out of the thirty evaluated had significant and relevant differences. Freshman students have better information than seniors on topics related
to Government politics of a country\textsuperscript{4}, the relationship of technology in daily life\textsuperscript{5}, classification schemes, and the nature of the assumptions in science, the interdependence of science and technology and its effect on quality of life.

CONCLUSIONS AND IMPLICATIONS

The analysis of the differences between freshman and seniors students allow us to value the efficiency of college education in science and technology to understanding the NoS&T. The empirical evidence does not enable to establish that such studies improve significantly the understanding of Nos&T. The total number of sentences, categories and items that had relevant positive differences is low when comparing them with the 30 variables analyzed. Some comparisons present significant negative differences, that is to say that the understanding of the NoS&T gets worse over the school years. As a result of a variational analysis, it is stipulated that, based on COCTS, college education in these six countries has no impact on attitudinal change in the relationships to STS. These considerations have to be taken into account as an explicit purpose in college curriculums.

REFERENCES


\textsuperscript{4} Freshman students, for example, think scientists are influenced by the politics of their country, because governments set policy for awarding research funds to some scientific research projects and not to others (Sentence, 20141B).

\textsuperscript{5} Freshman students say the systematic reasoning learned in science classes allows them to solve problems and understand a wide variety of physical events (Sentence, 40421C).
UNDERGRADUATES’ BELIEFS ON THE NATURE OF SCIENCE: A COMPARISON BETWEEN SCIENCE AND HUMANITIES

Mayra García-Ruiz¹ y Alejandro Cid del Prado²

¹Universidad Pedagógica Nacional (México)
²Universidad Mexicana

Abstract: The purpose of this research was to analyse undergraduate science and humanities students’ beliefs on the nature of science and technology (NoST). The study was carried out with 1037 Mexican first graders and senior college students. The instruments used are the Questionnaire of Opinions on Science, Technology and Society two formats (Manassero & Vázquez, 1998). Overall, both groups of students (science and humanities) showed bad informed beliefs of NoST and in several cases, humanities students’ showed beliefs more informed than science students, mainly on issues related to science and technology in society, such as social responsibility for pollution, conception of technology, and features of the scientific community. These results show that science students are not receiving enough training in science, as they are not showing a better understanding about NoST. This study could be the basis for design proposals to improve science and technology education.

Keywords: Nature of science, science-technology-society, undergraduate students’ beliefs, science and humanities.

BACKGROUND

There are several problems underlying nature of science and technology teaching. One problem stems from the beliefs about S&T, most of students and teachers have uninformed and inappropriate views about science, scientists, scientific method, and scientific work. Furthermore, exists a reductionist view of technology and misunderstanding its relationship with society and environment.

FRAMEWORK

The main goal for science education in the last few decades has been the students developing informed views of nature of science (NOS); a wide research it has been carried out, mainly with basic education students (Abd-El-Khalick & Lederman, 2000; Lederman, 1992). However relatively little attention has been paid to college students’ NOS views. Review of the literature has shown different findings about nature of science, some studies have assessed the nature of scientific knowledge views held by college students with different majors, for example Schommer (1993) showed that epistemological views of social science at majors were less sophisticated than those of technological science majors. Other researchers like Jehng, Johnson, and Anderson (1993) found that students in social sciences and humanities were more likely than engineering and business students to view knowledge as uncertain. These findings emphasize the relevance to assess and take into account the beliefs and attitudes about NoST.

RATIONALE

According to some authors (Abd-El-Khalick, 2006; Lederman, 2006; Abd-El-Khalick & Lederman, 2000) exploring the meanings that college science students ascribe to various
aspects of NOS is significant because a good understanding of NOS is an essential component of scientific literacy, which is a goal for all citizens in participatory democracies (AAAS, 1990; NRC, 1996). In addition, research on teaching and learning about NOS in K-12 and science teacher education indicates that the assumption that students learn about NOS implicitly through engagement in science based activities is not empirically valid (Abd-El-Khalick & Lederman, 2000). That is, NOS should be taught involving the students in discussions about science activities and their implications for resulting knowledge (Lederman, 2006).

Besides, the college students will join the economic and politically active population of the country.

PURPOSE

Thus, this study was aimed to explore and to compare the beliefs about nature of science and technology and their relations with society and environment, between sciences and humanities Mexican freshmen and senior college students. It was expected that science students would have better understanding about NoST than humanities students.

METHODS

Participants were 1037 Mexican college students in sciences and humanities (60% females and 40% males). Their ages ranged from 18 to 43 years (M = 22.7 years, SD = 3.9 years). At the time of the study 495 participants were freshmen and 542 seniors. PIARCTS project has a common methodology explained elsewhere (Manassero & Vázquez, 1998). The two selected fifteen questions formats of the Questionnaire of Opinions on Science, Technology and Society (COCTS for Spanish acronymus, available on http://www.oei.es/COCTS/) were applied to the participants in the study. The variables analysed were science and humanities majors and undergraduate level (freshmen and seniors).

RESULTS

Overall results showed two important things: 1) the most of the positive indices corresponded to the appropriate phrases and negative indices to the plausible and naïve phrases, both in science and humanities students, and 2) The phrases with the highest positive indices coincided with the classification of the panel of experts who examined these items. This means that participants were able to identify appropriate beliefs that reached a consensus by the scientific community.

Beliefs about NoST in science and humanities freshmen

The comparison between science and humanities’ students of the first year showed only one significant difference on the epistemological dimension, specifically in the naïve phrase referred to the scientific models used in research laboratories are copies of reality, because much scientific evidence has proven them true; students of both groups had negative indices, science students showed more negative rates (M = -.7159 ± SD .338) than humanities students (M = -.2698 ± SD.580, p <.0005). These findings showed uninformed beliefs in both groups of students and showed the weaknesses about these issues.

Beliefs about NoST in science and humanities seniors

In the case of seniors (see table 1) both groups of students showed erroneous concepts about technology (phrase F2_10211B_I), they agreed that technology is the application of science, the indices more negatives were presented by science students; regarding to improve the quality of living, it would be better to spend money on technological research RATHER THAN scientific research (F2_10421_A_I), science students showed better score than
humanities seniors; concerning to the involvement of private companies in science (F2_20211D_P) both groups had negatives scores, but science students presented the most inappropriate answer for the plausible phrase. However, in the case of adequate phrase (F2_20211E_A), science senior students manifested a more informed views; in relation to who must to make the social decisions about scientific issues, just scientist or the decisions must be shared with society (phrase F2_C40211B_I scientists and engineers should decide because they have the knowledge and can make better decisions than government bureaucrats or private companies, both of whom have vested interests), both groups had uninformed views, but again science group had more negatives results than humanities group. With respect to application of science and technology knowledge to daily life (F2_40421C_A), both groups of seniors manifested appropriate and positive views and science students had better scores in adequate phrase. Respecting scientific models, both, science students and humanities students said that scientific models are copies of reality because much scientific evidence has proven them true (F1_C_90211B_I). But like the freshmen, science seniors showed a more negative average than humanities students. In regard to classification schemes developed by scientists (F2_90311D_A), both groups had positive scores, though science students showed more informed beliefs than humanities students.

Table 1. Beliefs about NoST in science and humanities Students

<table>
<thead>
<tr>
<th>Phrases</th>
<th>Students</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2__10211B_I_Technology (the application of science).</td>
<td>Science</td>
<td>-.6610</td>
<td>.4613</td>
<td>.006</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td>-.4238</td>
<td>.5980</td>
<td></td>
</tr>
<tr>
<td>F2_C_10421A_I_Interdependence (improve the quality of living, it would be better to spend money on technological research RATHER THAN scientific research).</td>
<td>Science</td>
<td>.3966</td>
<td>.6248</td>
<td>.007</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td>.1235</td>
<td>.6694</td>
<td></td>
</tr>
<tr>
<td>F2__20211D_P_Industry (S&amp;T should not be headed by private companies (because scientific discoveries would be restricted to those discoveries that benefit the corporation (for example, making a profit). Important scientific discoveries that benefit the public are made by unrestricted pure science)</td>
<td>Science</td>
<td>-.5000</td>
<td>.6088</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td>-.2012</td>
<td>.6955</td>
<td></td>
</tr>
<tr>
<td>F2__20211E_A_Industry (because corporations would obstruct scientists from investigating important problems which the companies wanted kept quiet; for example, pollution by the corporation).</td>
<td>Science</td>
<td>.7026</td>
<td>.4329</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td>.3918</td>
<td>.6061</td>
<td></td>
</tr>
<tr>
<td>F2_C_40211B_I_Social decisions (scientist and engineer should decide).</td>
<td>Science</td>
<td>-.5127</td>
<td>.5988</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td>-.2209</td>
<td>.6709</td>
<td></td>
</tr>
<tr>
<td>F2_40421C_A_Application to daily life (Science classes sometimes help to solves practical problems).</td>
<td>Science</td>
<td>.6441</td>
<td>.4335</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td>.4009</td>
<td>.5487</td>
<td></td>
</tr>
<tr>
<td>F1_C_90211B_I_Scientific</td>
<td>Science</td>
<td>-.4271</td>
<td>.4865</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td>Humanities</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
models (are copy of the reality because much scientific evidence has proven them true).

F2_90311D_A Classification schemes (There are many ways to classify nature, but agreeing on one universal system allows scientists to avoid confusion in their work).

<table>
<thead>
<tr>
<th>Format 2</th>
<th>Effect size</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2_20211_E_A Industry (should not head science because if corporations did, corporations would obstruct scientists from investigating important problems which the companies wanted kept quiet; for example, pollution by the corporation).</td>
<td>0.7913</td>
<td>0.01</td>
</tr>
<tr>
<td>F2_40421_A_I Application to daily life (S&amp;T solving everyday problems)</td>
<td>1.05</td>
<td>0.000</td>
</tr>
<tr>
<td>F2_90311_D_A Classification schemes (There are many ways to classify nature, but agreeing on one universal system allows scientists to avoid confusion in their work).</td>
<td>0.7383</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Freshmen and senior science’ beliefs

We found some significant differences between freshmen and senior science students’ beliefs. In the adequate phrase referent to industry should not head science, because if corporations did, corporations would obstruct scientists from investigating important problems which the companies wanted kept quiet; for example, pollution by the corporation, seniors showed significant higher scores than freshmen; in the phrase related to S&T solving everyday problems (application to daily life, F2_40421_A_I), both science groups had negative indices, but science seniors showed the most negatives. The last sentence in which significant differences were observed pertains to the classification schemes for nature that scientists use (i.e. F2_90311_D_A There are many ways to classify nature, but agreeing on one universal system allows scientists to avoid confusion in their work); in this case both groups had positive views, although seniors performed better than first-years, in the table 2 is shown the effect size of differences.

Table 2. Effect size and significant differences between phrases indices of freshmen and seniors sciences.

<table>
<thead>
<tr>
<th>Phrases</th>
<th>Format 2</th>
<th>Effect size</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2_C_10421A_I Interdependence</td>
<td>-.0093</td>
<td>.60184</td>
<td>.1235*</td>
</tr>
</tbody>
</table>

Humanities students’ beliefs

When we analysed the beliefs of humanities students we found a higher number of significant differences between freshmen and seniors, which are shown in table 3.

Table 3. Means, standard deviation and significances among humanities first-year and last-year students related to NoST beliefs.
<table>
<thead>
<tr>
<th>Phrase</th>
<th>Mean</th>
<th>Std Dev</th>
<th>t Value</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1_C_20141I_I Country’s government policies</td>
<td>.2524</td>
<td>.68971</td>
<td>3.471*</td>
<td>.000</td>
</tr>
<tr>
<td>F1_C_30111G_I STS interaction</td>
<td>.3125</td>
<td>.62935</td>
<td>3.745*</td>
<td>.003</td>
</tr>
<tr>
<td>F2_C_40131G_I Social responsibility information</td>
<td>.0031</td>
<td>.63717</td>
<td>2.317*</td>
<td>.004</td>
</tr>
<tr>
<td>F1_C_40161A_I Social responsibility contamination</td>
<td>.1887</td>
<td>.70793</td>
<td>3.302*</td>
<td>.000</td>
</tr>
<tr>
<td>F2_C_60521H_I Gender equity</td>
<td>.2428</td>
<td>.67613</td>
<td>4.909*</td>
<td>.002</td>
</tr>
<tr>
<td>F2_20211C_P Industry</td>
<td>.0586</td>
<td>.62906</td>
<td>-1.126</td>
<td>.265</td>
</tr>
<tr>
<td>F1_C_40531A_I Life welfare</td>
<td>-.2859</td>
<td>.58731</td>
<td>-1.1307</td>
<td>.142</td>
</tr>
<tr>
<td>F2_90111C_I Observations</td>
<td>-.3610</td>
<td>.50143</td>
<td>-1.1702</td>
<td>.064</td>
</tr>
<tr>
<td>F2_C_90521A_I role of assumptions</td>
<td>-.3198</td>
<td>.56997</td>
<td>-1.1174</td>
<td>.042</td>
</tr>
</tbody>
</table>

*Indicates phrases where seniors got higher scores than first-year ones.

In most of the phrases last-year humanities students showed more favourable beliefs than beginners, including those sentences where both groups had scores either positive or negative, seniors had more positive or less negative scores. For example in the first phrase, F2_C_10421A_I Interdependence quality of life (i.e. for improve the quality of living, it would be better to spend money on technological research RATHER THAN scientific research), the last-year students had positive and appropriate views, meanwhile the first-year participants had negative indices. The second phrase F1_C_201411_I is referred to how Scientists are NOT affected by their country’s government policies: because scientific research has nothing to do with politics. Again humanities seniors had more positive scores. In the next naïve phrase (F1_C_30111G_I) about the interactions among STS, the humanities students disagree with the idea that there is just a light relationship among science and society –as shows this phrase-, they think that exist a mutual interaction between STS, although they are not so sure about the intensity between them, mainly first-year students. With regard to social responsibility with information (F2_C_40131G_I) that is the social responsibility of the scientist to inform their findings to the general public in a manner that the average citizen can understand (Scientists should NOT be held responsible since the public often does not seem to care. It’s up to the public to learn enough science to understand the reports), once more seniors manifested beliefs more informed. Respecting to F1_C_40161A_I Social responsibility with contamination: Both groups of humanities students had appropriate views and showed social responsibility, they disagree with the heavy industry should be moved to underdeveloped countries to save others countries, they think that It doesn’t matter where industry is located. The effects of pollution are global and moving industry is not a responsible way of solving pollution. We should reduce or eliminate it. However, even though both groups had positive scores, seniors had better indices. And the phrase F2_C_60521H_I of Gender equity (Women would do science somewhat differently because, by nature or by upbringing, females have different viewpoints, perspectives, imagination, or characteristics - such as patience-), both groups of humanities students showed appropriate belief, but first-year students had lowest indices. These results show the effect of training.

The phrase F2_20211C_P Industry it is noteworthy that freshmen had better scores than seniors. Finally, in the last three phrases showed in the table, like F1_C_40531A_I Life welfare (referred to more technology will improve the standard of living of the country, because technology has always improved the standard of living, and there is no reason for it to stop now, F2_90111C_I Scientific observations will not differ very much even though scientists believe different theories. If the scientists are indeed competent their observations
will be similar, and F2_C_90521A_I_ the role of assumptions for the development of the theories or laws that is assumptions MUST be true in order for science to progress: because correct assumptions are needed for correct theories and laws. Otherwise scientists would waste a lot of time and effort using wrong theories and laws, the two groups of humanities had negative indices. These negative means corresponded to naïve and plausible phrases and even though in these cases both groups of students show uninformed beliefs, last-year students performed better than beginners.

CONCLUSIONS AND IMPLICATIONS

The results of this study allowed us to identify important NoST teaching and learning elements. This assessment is the basis to design proposals to improve the science and technology education.

In general terms the results showed that college students’ beliefs were fragmented and it can be seen a lack of strength in their knowledge. In addition, the most of participants exhibited naïve beliefs and inaccurate understanding about NoST, which confirm previous investigations (Abd-El-Khalick, 2006). The subjects in which college students’ had more accurate beliefs were related to social responsibility to pollution and information, and to equality of women and men in science. But they lacked experience in technology concept, scientific community feature and STS interactions.

In this research it was expected that training and experience related to science contributed to a better understanding of the NoST. These results do not support totally this hypothesis. Because working with science and humanities students, we noticed that the humanities students showed more informed and elaborated beliefs than the science ones. Only in a few cases, science students demonstrated better scores than humanities students. We observed naïve beliefs in all groups of students, but contrary to expectations, it was in the science groups where the views resulted less informed and they had lower ability to link science and technology with society. Besides science students had more naïve beliefs overestimating the role of S&T on society and minimizing the role of society on S&T; a possible explanation about these findings could be the influence of previous learning experiences and reflect more entrenched naïve views about S&T. Science students’ views of NoST would have been affected by a traditional positivist approach to interpreting what constitutes science. In addition, humanities students’ have a strong socio-cultural training by which these students showed a better performance in these aspects. These finding were unexpected, by which we consider that is very important to carry out a deeply analysis of these results. The significant differences on NoST beliefs among science and humanities’ Mexican students proven that students with different major backgrounds have slightly different scientific epistemological beliefs, confirming previous results (Liu & Tsai, 2008) and contrasting with those reported by Schommer (1993), since in our study science students did not have more sophisticated views about science issues. Our findings make evident that the programs of science are not taking into account important aspects of the nature of science, because the senior science students are not showing a better understanding of these issues. It is necessary to address in an explicit and concrete way these contents, as Lederman (2006) has pointed out, the nature of science contents should be presented in a reflective manner and need to be taught as other more traditional cognitive outcomes.

The Mexican science curriculum includes content on NoST such as the study of nature, science and technology, its applications and relations with society, considering benefits and problems in society and the environment. The science students’ beliefs indicate a lack of substantive elements as the relationship between socio-economic, political and ethical issues with NoST aspects. On the contrary, in humanities students there were several differences
among freshmen and seniors, and in most cases seniors showed more informed and appropriated beliefs.

These data can be very useful because, in conformity with Liu & Tsai (2008), in this research we also deemed that understanding the students’ epistemological views could offer valuable information for the design of graduate and undergraduate courses to improve students’ science epistemological views and provide us with some clear direction in terms of future research and teaching proposals.

Finally, we consider that much more work is needed to develop a better NoST understanding in all college students, not only in science students, because in our society every citizen should be able to make informed decisions about those issues and then to build a better relationship with the environment.

REFERENCES


Acknowledgement

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IS THE ATOM REAL OR BUILT? OR IS IT AN INTERMEDIATE BETWEEN THESE TWO? A WITTGENSTEINIAN APPROACH.

Jackson Gois¹,² and Marcelo Giordan²

¹ Department of Chemistry – Universidade Federal do Paraná – Brasil
² Faculty of Education – Universidade de São Paulo – Brasil

Abstract: The question about whether the atom is real or built is still among us despite the scientific and philosophical efforts already made. In this work we propose a solution to this question based on the philosophy of Wittgenstein, looking on how we use language. Wittgenstein’s thought is considered of crucial importance in twenty century philosophy. Despite the importance of his philosophy, which helps us to think about concepts, language and meaning, nowadays there are few contributions of Wittgenstein’s ideas in science education. We challenge the idea of asking questions directly about the atom out of a model and try to put real and building in the right place in scientific practice. We discuss about models, data and natural phenomena, and try to understand them in terms of real and built. Instead of trying to answer this question, we dissolve it, remembering what exists and what is built in scientific practice. Wittgenstein’s philosophy, as an exercise to a closer look on how we use language, is useful to understand philosophical aspects of chemistry and science education. We must not fear or be angry with either existence or building. It is only necessary to put each one of them in their right place. We think it is an interesting educational solution to this problem, as students will start to see that some usual questions may be illusory.

Keywords: Wittgenstein, Science Teaching, realism, constructivism, philosophy of language

INTRODUCTION

It is quite clear by now that Wittgenstein (2001) wrote about philosophy, more specifically the language illusions that philosophers had been chasing for some centuries thinking it were big truths. Wittgenstein’s thought is considered of crucial importance in twenty century philosophy. His contribution has influenced the linguistic turn in philosophy and also many other disciplines. These contributions, like his anti-essentialist approach and his methods of pointing to language illusions where philosophers have been trying to find grounds, are still a challenge to those dedicated to an in deep understanding of his thought. His important philosophy helps us to think about concepts, language and meaning, and nowadays the contributions of Wittgenstein’s ideas in Science Education research can be found in influential epistemologies inspired on his philosophy (Wickman and Östman, 2004). The questions about the existence of the atom are important in chemistry courses and teacher training courses. Our main focus is to present a contribution on this subject based on Wittgenstein’s philosophy. As well as the philosopher, we want to show that some expressions in Chemistry and Science Education are misleading, and have guided us to ask
illusory questions on both fields. In particular, we want to show a philosophical solution, in a wittgensteinian fashion, to the old problem of asking whether atoms are real or built, or even an intermediate between these two positions. We have no intention in finishing this philosophical question, as we are talking to a Science Education community.

It is necessary to observe at first that we, in Science Education research, are not doing any Philosophy of Science research. In fact, in Science Education many historical aspects of Philosophy of Science help us to show the way scientists do science, and these aspects are also interesting to introduce students to important questions in Science Education. Nevertheless, we are always challenged by questions from the Philosophy of Science research field. One of those is the famous question about the existence of the atom. Do atoms exist or are they constructions of our senses? Can we say that atoms are real, for example, in a scientific reality, in opposition to a naïve reality, or the dependence of our senses wouldn’t allow us to do such assertions?

The first big congress of chemists took place in Karlsruhe (Nye, 1996). This event gave visibility to Chemistry, and one of the goals was to define general rules to this discipline. One of the main questions was on the divergence of the uses of terms like atomic weight and atomic equivalent. It was a philosophic question between atomists and anti-atomists, and the background was the existence of the atom. But there was no confrontation between these two groups in that moment, as chemists needed to defend their position against the mecanicist naïve realism of physicists. And this dispute has been renewed in many other flavors, like the dispute between Ostwald’s energysm and Boltzmann’s realism that ended in 1906 in favor of the late.

More recent disputes on the existence of the atom are about of what representation actually represents, among other topics. Ghins (2010) discusses about the applications that Bas van Fraasen does of Foucault’s proposals, when the late challenges the idea that knowledge is representation. Ghins defends a scientific realism, and asserts that models do not represent completely natural phenomena. Giere (2006) defends a perspectivist realism, which accord to him would be between realism and constructivism. In his arguments he claims that scientific propositions are neither as objective as objectivist realists want, nor as socially determined as moderate constructivists think. The only fact collectively recognized here is that this surely is a philosophical problem because no more data will solve this old quarrel. In this work we want to analyze the questions, instead of choosing one of the answers.

**REAL OR BUILT?**

Before our reader accuses us of realism or constructivism, we ask for patience to read our text in full length. We will start with an ordinary question as an example of what we are going to talk, and after that, we will start thinking about our specific subject. Does Santa Claus exist? Of course not, most of human beings would answer. But if we are able to talk about him, so in some sense he exists. Philosophical puzzlement many times starts like this. A wittgensteinian answer to this question would be that we are talking about two similar, but different ways of existing. Concepts, models or stories do not exist in the same sense as mountains or natural phenomena. Some philosophers, when asking about this two different existences as if they were one, forget that we, human beings, invented the Santa Claus story, but we did not invent natural phenomena, although we invented ways of thinking and talking about them. And we can use the word exist for both, but with different meanings.

From this point we remember a curious fact about the questions of the atom existence: We don’t remember someone has ever asked us about the existence of Rutherford’s atom, or
Sommerfeld’s atom, or any other model’s atom. The question about the atom existence is always made as if it was possible to talk seriously about it out of a given model. We forget that it is not possible to ask anything about the atom out of a model. Let’s try, for example, to ask something about the relationship between electrons and the nucleus in an atom. One would immediately ask: in what atomic model? This would be so because, if we think about Dalton’s atom, there is no such a relationship, once there is no electron. And these relationships would differ enormously from model to model. It is not possible to ask if the atom, out of a model, is real or built, just because there is no atom out a model. As chemists and physicists most of us keep talking about atoms without specifying a model, just because it is implicit in the properties that are on the subject. This leads us to the illusion that it is possible to ask questions directly about the atom.

What is built in science?

We believe no serious researcher think that any atomic model was not built. So, the atom of Rutherford is a model built by us, as well as any other atomic model. We built these models from the data available in the circumstances, and also from any other historic and scientific circumstances. These models were built to explain data, and also to understand better natural phenomena and some of its properties. So, it is an illusion to ask about the existence of the atom, out of a model, because no one doubts that all models were built. It follows that atoms, in a given model, are built. We must not feel that scientific knowledge is threatened because we use models as constructions. We just have to put it in the right place.

What is real in science?

At this point maybe the reader is thinking we are going to defend a constructivist approach, but this is not the case. Someone would be inclined to think like this so far in this text because, at the end, we work with science, and there is plenty evidence about the properties of the models we have built. So, something must exist! It is not correct to say that atoms exist, because there is no atoms out of a model, but as practitioners of experimental sciences we also don’t believe that the world that surrounds us is a mere convention. So, is it possible to speak that something exists? If so, what is this? Is it a reality behind or beyond our senses?

First, is it possible to speak that the data we collect exist, in a strict sense? We don’t think so. The data we collect depend upon methods of collecting data, knowledge of how to deal with numbers, charts and other way of representing, and many times it is possible to collect different sets of data from the same natural phenomenon. Our data are also built, in the sense we have to collect them, as well as we have to arrange them in a proper way of representation.

So, are our data mere conventions? Here we have to remember that there are at least two aspects of data. The first one is about the constructs and representations we invented to deal with quantities, and upon what we take data. The second is that when we take data, it is a way to represent some aspects of a phenomenon that exists without human interference. So, about the question of our data being a convention, the answer is yes in the sense about the way we write it, and no in the sense they mirror some aspects of natural phenomena. These are two different aspects, and sometimes we treat them as if they were just one. We are not defending that data are conventions, but that its representation is a convention. And we are not defending that data is real, but that it represents some aspects of a real phenomenon. The data may be seen as a mirror of some aspects of natural phenomena, but cannot be considered real in a strict sense, like the natural phenomena itself. In any case, we can say that our data is built.
But, does anything exist anyway? To understand better about the existence of the world that surrounds us, we have also to remember from what point most of scientific discourse has emerged: understanding natural phenomena. Natural phenomena are the only thing we can say to exist, in a straight sense. No one should doubt about the existence of natural phenomena, as well as no one usually doubts about the existence of the front door of his or her house. It is senseless to believe the existence behind or beyond our senses both to natural phenomena and our door. It is also senseless to doubt their existence. They just exist. So, it should not be necessary to ask if either of them exist. We think, thought, it is important to stress that the only existence we can talk about, is of natural phenomena. But the existence of natural phenomena in atomic and molecular level and the evidences about the laws of matter do not give us the right to state that the models we invented exist. Models and data are built. We must not feel that scientific knowledge is threatened because models and data are not real in a strict sense. We just have to put real in the right place, and this place, we believe, are natural phenomena, although data mirrors some aspects of it.

The illusory question

So, the question about the existence or building of atoms is put as if it was two conflicting positions, and you had to commit yourself with one of them. Or worse, maybe there should be an exhaustive mental exercise to find an intermediate position between these two, or even to find a third way of explaining the fact that we build models and are able to talk about natural phenomena. We hold that none of these positions are satisfactory, because in all of them we just forget how we use the words real and built in everyday life. And if we want to give them new meaning, let us say clearly what meaning is this. It is philosophically misleading to ask a question in a broad sense, e.g. if something is real or built, and expect a specific sense. All we need to do is to remember what is real and what is built in scientific practice, and that it is not possible to talk seriously about atoms without specifying a model.

Conclusions

The question about whether the atom exists or is built is a double illusion. What is built is the atom of a given model and data, and what exists are natural phenomena. So, the atom of, say, Rutherford’s model, is built, although the natural phenomena in atomic and molecular scale, from where both data and model were obtained, is real. The question put forth in the title cannot be answered because it is philosophically misleading and senseless. Instead of trying to answer this question, we tried, in this short work, to dissolve it, remembering what exists and what is built in scientific practice. Wittgenstein’s philosophy, as an exercise to a closer look on how we use language, is useful to understand philosophical aspects of chemistry and science education. We must not fear or be angry with either existence or building. It is only necessary to put each one of them in their right place. We think it is an interesting educational solution to this problem, as students will start to see that some usual questions may be illusory.

REFERENCES


DETERMINATION OF STUDENTS’ MODEL COMPETENCE USING OPEN-ENDED AND HANDS-ON TASKS

Juliane Grünkorn1, Juliane Hänsch2, Annette Upmeier zu Belzen2 & Dirk Krüger1
1 Freie Universität Berlin
2 Humboldt-Universität zu Berlin

Abstract: Models are an important part of scientific thinking and working methods. Thinking in models enables people to communicate about difficult scientific topics and to reach a consensus. Therefore, scientific thinking and working methods cannot be learned without models (Harrison & Treagust, 2000). However, various studies have shown that most of students’ conceptions of models and modeling differ from scientific conceptions (e.g. Grosslight et al., 1991). To describe scientific and everyday conceptions, Upmeier zu Belzen & Krüger (2010) have developed a theoretical structure of model competence. First of all, this theoretical structure needs to be evaluated empirically.

The aim of the presented research projects is to evaluate the theoretical structure using open-ended and hands-on tasks. These different approaches make it possible to cover different facets of model competence concerning thinking in and handling of models (White & Gunstone, 1999).

To achieve this objective, fifteen tested open-ended tasks (Grünkorn et al., 2011) were used and data were collected from a total of 1180 students (grade 7-10). The data were analyzed by qualitative content analysis (Mayring, 2007) to identify different students’ conceptions of models and modeling (categories) and to compare them to the theoretical structure. A following study with two evaluated hands-on tasks (Hänsch & Upmeier zu Belzen, 2011) was conducted with four students. 135 student answers given while thinking aloud and during interviews were coded thematically (Hopf, 2001) by assigning the answers to the categories of the open-ended tasks.

The analysis of the student answers shows that the majority of the students’ answers are consistent with the theoretical structure. However, the findings revealed that additional facets in the theoretical structure need to be considered. Some categories of the open-ended tasks show hands-on specific expressions.

Keywords: Models, Nature of Science, Model Competence, Open-Ended Tasks, Hands-On Tasks

INTRODUCTION

Models in science are not only resources to teach scientific knowledge, but are also scientific thinking and working tools to generate new knowledge (Mahr, 2009; Upmeier zu Belzen & Krüger, 2010). Various studies have revealed that students reflect little on their thinking in and handling of models and that they are not aware of the role models play in epistemological processes (e.g. Grosslight et al., 1991). PISA 2000 (Artelt et al., 2001) and 2003 (Prenzel et al., 2004) show that German students have difficulties in tasks where the handling of and thinking in models are essential to solving a problem. These results initiated a broad debate about the quality of the German school system (Klieme et al., 2003) whereby normative competencies were defined (KMK, 2005). In biology education, five out of thirteen competencies deal with handling models reflectively in the field of scientific inquiry (KMK, 2005).
To foster students’ reflective handling of and thinking in models adequately, scientific and everyday conceptions of models and modeling need to be related and structured theoretically. Upmeier zu Belzen and Krüger (2010) have developed a theoretical structure of model competence describing skills and abilities required for this aim. This structure could serve as a theoretical basis for the development of diagnostic instruments. However, this theoretical structure needs to be tested empirically which is the objective of the presented research projects.

THEORETICAL BACKGROUND

Upmeier zu Belzen and Krüger (2010) designed a theoretical structure of model competence (Table 1) according to empirical studies (Grosslight et al., 1991; Justi & Gilbert, 2003; Crawford & Cullin, 2005) and the view of models in philosophy of science (e.g. Mahr, 2009). It entails two cognitive dimensions: The dimension ‘knowledge about models’ with the aspects ‘nature of models’ and ‘multiple models’ describing individual concepts that are applied when dealing with models. And the dimension ‘modeling’ with the aspects ‘purpose of models’, ‘testing models’, and ‘changing models’ which describe the handling of models concretely.

Each aspect is further divided into three levels representing different reflection levels. So far, these levels have not been described as developmental levels (Upmeier zu Belzen & Krüger, 2010).

Table 1: “Theoretical structure of model competence (Upmeier zu Belzen & Krüger, 2010)”

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge about models</td>
<td>replication of the original</td>
<td>idealized representation of the original</td>
<td>theoretical reconstruction of the original</td>
</tr>
<tr>
<td>Nature of models</td>
<td>differences between different model objects</td>
<td>the original allows the creation of different models</td>
<td>different hypotheses about the original</td>
</tr>
<tr>
<td>Multiple models</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modeling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purpose of models</td>
<td>describing the original</td>
<td>explaining investigated relationships</td>
<td>predicting connections between variables</td>
</tr>
<tr>
<td>Testing models</td>
<td>testing the model object itself</td>
<td>comparing the model with the original</td>
<td>testing hypotheses about the original with the model</td>
</tr>
<tr>
<td>Changing models</td>
<td>correcting errors in the model object</td>
<td>revising the model due to new findings about the original</td>
<td>revising the model due to falsification of hypotheses about the original with the model</td>
</tr>
</tbody>
</table>

OBJECTIVE

Since this theoretical structure of model competence (Upmeier zu Belzen & Krüger, 2010) has not been empirically tested yet, the aim of the two presented research projects are to evaluate this theoretical structure using open-ended (Grünkorn et al., 2011) and hands-on tasks (Hänsch & Upmeier zu Belzen, 2011).
Both task formats are used to determine different facets of model competence: Open-ended tasks are suitable to determine students’ cognitive concrete and general conceptions of models and modeling of a larger sample (Mayer et al., 2008). Hands-on tasks are used to measure – apart from cognitive abilities – procedural knowledge and manual skills (Hamilton et al., 1997). These different approaches make it possible to cover different facets of model competence concerning thinking in and handling of models (White & Gunstone, 1999).

RESEARCH QUESTIONS

The tested open-ended and hands-on tasks were used to evaluate the theoretical structure of model competence (Upmeier zu Belzen & Krüger, 2010). Regarding this aim, the following research questions are posed:

• To what extent are the students’ conceptions of models consistent with the theoretical structure of model competence?

• Which additional students’ conceptions of models to the theoretical structure of model competence can be identified using open-ended and hands-on tasks?

RESEARCH DESIGN AND METHODS

Open-Ended Tasks

To answer these research questions, 15 open-ended tasks were used and tested in preceding studies for understandability and adequate operationalization to the theoretical structure (Grünkorn et al., 2011). Each open-ended task consists of a short task context, a visualized biological model, and a standardized instruction (Table 2). The tasks were designed in a way that students should be able to give answers at all levels.

Table 2. “Standardized instructions for each aspect”

<table>
<thead>
<tr>
<th>Dimension about models</th>
<th>Aspect</th>
<th>Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Nature of models</td>
<td>Describe the extent to which this model looks like the original.</td>
</tr>
<tr>
<td></td>
<td>Multiple models</td>
<td>Explain why there are multiple models for one original.</td>
</tr>
<tr>
<td>Modeling</td>
<td>Purpose of models</td>
<td>Describe what purpose this model serves.</td>
</tr>
<tr>
<td></td>
<td>Testing models</td>
<td>Explain in detail how people can test if the shown model serves its purpose.</td>
</tr>
<tr>
<td></td>
<td>Changing models</td>
<td>Explain in detail what could have happened so that this model will be changed.</td>
</tr>
</tbody>
</table>

Since one student could not answer all tasks, the task pool was distributed in 35 test booklets (multi-matrix design). The study was conducted with 1180 7th to 10th-grade students aged between 11 and 19 years old to obtain student answers at all three levels. The data were analyzed by qualitative content analysis according to Mayring (2007): In an inductive approach, similar student answers were structured and categories were generated describing different students’ conceptions of models and modeling. Subsequently, the categories were assigned to the three levels of the theoretical structure (deductive approach). If a category could not be assigned to the theoretical structure, it was added to the aspect of the theoretical structure. This categorization enabled a detailed description of each aspect.

To evaluate the assigned student answers, additional raters were consulted. The assigned student answers from two raters were compared and differences were discussed until a
consensus was reached (Gropengießer, 2001). If a student answered in different categories or levels, all categories and levels were noted.

**Hands-On Tasks**

Two hands-on tasks were designed based on the process of scientific modeling by Justi and Gilbert (2002) and the theoretical structure of model competence (Upmeier zu Belzen & Krüger, 2010). The structure of hands-on tasks consists of different oral and written parts that encourage students to investigate a biological phenomenon by building their own models. At the beginning of the hands-on tasks, students generate own questions to the presented phenomenon. In order to find hypothesis and plan the examination, important information about the phenomenon is given. Resulting mental models are recorded using a drawing (Gobert & Pallant, 2000). This is followed by the construction of a model with different materials and conclusions about the hypotheses. At the end of each task students are tested whether they can integrate new information about the original in own models. The structure of the hands-on tasks was evaluated by five experts on model competence regarding the adequate operationalization of the theoretical structure and by two linguists regarding the understandability of the tasks. So far, four students (grade 7-10) solved two hands-on tasks in 90 minutes.

Psychomotor skills and verbal aspects of model competence can be determined while solving hands-on-tasks using the multi-method interview. This method consists of three components: interview, thinking aloud and videography (Wilson & Clarke, 2004). Student statements given while thinking aloud and during interviews were coded thematically (Hopf, 2001) by assigning the answers to the categories of the open-ended tasks. The assignments of the student answers to these categories were conducted by two independent coders.

**RESULTS**

**Open-Ended Tasks**

Altogether, 38 categories could be described and the majority – 35 categories – could be assigned to the three levels of the theoretical structure of model competence. Table three shows the distribution of the student answers within all aspects of the theoretical structure. If a student answered in different categories or levels, all categories and levels were noted. The category ‘not evaluable’ represents student answers that did not answer or his/her answer did not correspond to the question.

<table>
<thead>
<tr>
<th>Aspect, Number of students</th>
<th>Frequency of students’ answers in absolute values (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not evaluable</td>
</tr>
<tr>
<td>Nature of models, n=697</td>
<td>75 (10.8)</td>
</tr>
<tr>
<td>Multiple models, n=705</td>
<td>158 (22.4)</td>
</tr>
<tr>
<td>Purpose of models, n=707</td>
<td>35 (5.0)</td>
</tr>
<tr>
<td>Testing models, n=711</td>
<td>58 (8.2)</td>
</tr>
<tr>
<td>Changing models, n=713</td>
<td>118 (16.5)</td>
</tr>
</tbody>
</table>

The percentage distribution of the aspects ‘nature of models’, ‘multiple models’, and ‘purpose of models’ shows that most student answers could be assigned to level I, followed by level II. Level III represents the lowest share. For the aspects ‘testing models’ and ‘changing models’ the majority of the students responded at level II, followed by level I. Only a few students gave answers at level III.
Some of the student answers that could not be assigned to the theoretical structure describe three additional perspectives that need to be considered: The aspect ‘multiple models’ is understood as one original is presented by different models. However, several students (n=106) justify the presence of multiple models with different originals or evaluate the shown models for correctness, as exemplified in the following. Those student conceptions were summarized to the category ‘one model for one original’.

**Student (Q352):** There are different models because there are different types of gullets. Additionally, the shape of the gullet can change after some years.

**Student (Q23):** I think that two of the three shown models are wrong and that only one model is right.

For the aspects ‘testing models’ (n=6) and ‘changing models’ (n=24) a number of students think it is unnecessary to test a model or think that the model does not change, for instance:

**Student (Q71):** Why do we need to test this model of a bug? I believe that this is unnecessary.

**Student (Q208):** In my opinion, this model does not change. The model is final.

**Hands-On Tasks**

135 student statements from interviews and thinking aloud could be assigned to the categories of the open-ended tasks. Therefore, hands-on tasks can be used for the determination of model competence. In this process, the hands-on tasks confirm the additional categories of the open-ended tasks. Most students make statements on level one and two concerning models as media, as to the open-ended tasks. Additionally, the hands-on tasks lead to reflection of models as tools to generate new knowledge, since many statements can also be assigned to categories on the third level of the theoretical structure. Further, because of the construction of own models, students understand them as idealized representations or theoretical reconstructions in the aspect ‘nature of models’.

A more detailed analysis shows hands-on specific expressions of some open-ended categories. The first relate to the function of the constructed model objects. For example, different functional principles of different model objects are described on the first level of the aspect ‘multiple models’:

**Student (Z41):** Maybe something works quite differently with a different model. Without this cover, it could fall down.

Another hands-on expression is related to the evaluation of the constructed model objects regarding to the proximity to the original, the achievement of the purpose, creativity, clearness and economy of materials:

**Student (A85):** I think the model is very clever ... This is also the most logical, because less material had to be used ... The sinking model is clearer than mine.

The following student statement clarifies recognition of a solidarity facet of knowledge acquisition with models, especially on the third level of the aspect ‘multiple models’:

**Student (A63):** There must be different models for the spinal column because there are people who think differently. Their reasoning will be different to mine. And we help each other through our thinking.
SUMMARY AND CONCLUSIONS
Concerning the percentage distribution of student answers shown in table three, Grosslight et al. (1991) and Crawford and Cullin (2004) note similar findings. Differences can be found for the aspect ‘testing of models’, showing that most students test a model while comparing the model object with the original (level I), whereas in the study of Grosslight et al. (1991) the majority of the students test the model itself to try something out. One possible reason for the prominent conceptions in level I and II of the theoretical structure might be a more frequent use of models as a substitute for the original or as a medium for transmitting information in biology lessons (e.g. Crawford & Cullin, 2004; Van Driel & Verloop, 2002).

Some open-ended task categories show hands-on expressions: For example, many statements relate to the function of constructed model objects because student hypotheses refer to the explanation of functions. Another hands-on expression, different student evaluations of the model objects, can be explained by the individuality of the modeling process (Justi & Gilbert, 2002). In addition, solidarity facets are visible in many student statements. The involvement of students in individual modeling processes leads to the reflection of scientific knowledge. Its social and cultural character (Lederman, 1992) can be deepened using hands-on tasks. Schwarz and White (2005) speak in this context of a metamodeling knowledge.

In both research projects three additional categories ‘one model to one original’, ‘no need for testing a model’, and ‘no need for changing a model’ could be described to the theoretical structure of model competence (Upmeier zu Belzen & Krüger, 2010). Similar results on the conceptions ‘one model to one original’, and ‘no need for changing a model’ are given by Justi and Gilbert (2003) and Crawford and Cullin (2005). In order to foster students’ reflective understanding of models and modeling adequately, it is important to know about these conceptions. Therefore, these perspectives need to be considered and might be added to the theoretical structure of model competence as an additional level.

REFERENCES


CREATING A MORE SOPHISTICATED STUDENT VISION OF THE NATURE OF SCIENCE: A SURVEY REPORT

Guerra Andreia¹; Braga, Marco¹ and Reis, José Claudio²
¹CEFET-RJ – University of Technology – Rio de Janeiro - Brazil
²UERJ – State University of Rio de Janeiro - Brazil

Abstract: Science teaching in high schools should stimulate students to understand the philosophical and cultural implications of scientific knowledge. One way to put this principle into practice is to develop curricula using a historical-philosophical approach. However, an investigation of textbooks and syllabuses in Brazil found almost no examples of this approach. This article discusses an educational experience developed in Brazil for students in a high school physics course. The course aimed to introduce a historical-philosophical approach starting with simple student inductive arguments about facts that precede theories. In this course, we introduced new activities and discussed historical-philosophical issues to create exercises incorporating this approach. We also introduced discussions about the worldview of each issue with dialogs about history, economy, arts, and others areas of human culture. Our goal was transforms students' views about science into something more complex. This pedagogical project does not significantly modify the structure of the physics course, but simply introduces conflicts at specific points in the course. The results showed that it is a useful method for including philosophical and historical discussions beyond anecdotal stories about science and scientists to a class.

Keywords: History of Science, Philosophy of science, Nature of Science, historical-philosophical controversies, experimentation.

INTRODUCTION

This research is part of the work developed by Tekne group in Brazil. Our aim is to develop research and pedagogical projects to stimulate students in secondary schools understanding the philosophical and cultural implications of scientific knowledge. The Teknê Group works since 1993 with the historical and philosophical approach in science education throughout the production of support texts.

In order to understand the philosophical and cultural implications of science, the students need to reflect about the process of elaboration of scientific knowledge throughout history (Braga, Guerra & Reis, 2010). Thus it is important to bring discussions about NOS to science's class. As far as we are concerned, the most critical question is: How to promote discussions about science in secondary schools?

This is not a new question. Some researchers have discussed it in last years (McComas, 1998). Some of them defend that the best way to put discussions about NOS in class is to develop activities in science classes which allows students understand the NOS without discussing explicitly aspects of NOS (Abd-El-Khalick & Lederman, 2000). Others defend that teachers have to put science in scrutiny in class, so, in this way, teachers have to develop activities that explicitly discuss NOS (Abd-El-Khalick & Lederman, 2000).
These considerations led us to develop a research with important data for this debate. Therefore, our research aims to answer the following question:

Is the introduction of historical-philosophical issues together with activities putting some element of NOS in scrutiny, a path that leads students to understand the philosophical and cultural implication of science?

To answer this question we’ve developed and evaluated a Physics course. But before the beginning of the course we had considered some key issues:

1- The scientists path to build knowledge are complex;

2- Scientific knowledge is build “throughout” dialogues among different knowledge.

These issues were confronted with the results of a survey developed previously with 173 students who attended the course. At this moment, the students answered an opened-end questionnaire with four questions. These questions were taken from VNOS-C questionnaire translated into Portuguese (Lederman et al., 2002). The four questions selected were related to experiences, creativity in science and the difference between law and theory. This survey data have shown that 73 % of students believe experimentation is a stage of scientific method that confirms the validation of a hypothesis; 63.6% of students believed that creativity is used only in the building of hypothesis; 14% said that scientists use creativity after data collection (although they pointed that creativity is used only when scientists do not have enough data to explain one phenomenon) and only 5% of them affirmed that creativity is part of all scientists’ work. It is important to mention that in the previous survey the students did not give any examples to confirm their ideas.

These considerations led us to concentrate upon the role of experimentation in science. So our aforementioned question has changed for:

Is the introduction of historical-philosophical issues together with activities that explore some aspects of NOS a path that leads students putting the role of science experimentation in scrutiny?

This question has guided the plan and the evaluation of the Experimentation Physics course. It is important to emphasize that our purpose is not evaluate the students’ visions change on science. Our goal is to create a more sophisticated vision of Nature of Science. With these ideas in mind we have planned the course.

**THE COURSE**

The course was carried on in an 11th grade class with 173 students divided in 5 classes. The students have two physics teacher. One of them was developed his lessons in laboratory and other in classroom. The present course was developed only in the laboratory. The students met the teacher each two weeks. The duration of each meeting was 100 minutes.

The students work in groups. Each group has four or five students. To identify each student and groups we used a code with two characters. The first one indicates the class (A, B, C, D and E). The second one shows the number of student in class.

To evaluate the course we chose a qualitative research approach. Photos and notes were collected during the lessons by teacher and another researcher. It is important to note that the teacher was part of the research team with other researchers.
The theme of the course was Thermodynamics.

We selected a specific historical moment to develop this work. This selection comes from a short book written by Teknê Group about “Lavoisier and the Enlightenment Science” (Braga et al, 2000)

We considered the data of another research develop by Tekne group about the introduction of historical controversies in science lessons to decide which moment to choose (Braga, Guerra, Reis, 2010). The data of this research led us to consider one interesting historical controversy that occurred in the 18th century: the Caloric Theory versus Phlogistic Theory.

How this controversy would contribute to the debate?

This controversy took place in the 18th century, so, it is important to note:

- Newton had unified the terrestrial and celestial Physics. And for many philosophers and scientists the Newtonian Physics model turned to be a good way to explain the world.
- The pharmaceutical and mineral industries growth stimulated the development of experimental science, like chemistry and electricity.
- Chemistry had in its framework elements of alchemy.
- Lavoisier, in France, and Priestley, in England, were investigating gases. They developed experiments to isolate new gases;
- Priestley and Lavoisier rejected metaphysics argument in science. Both believed that experimentation was the best way to build theories;
- Priestley explained his experiments based on the Phlogistic Theory. Lavoisier rejected this theory. For him, was necessary to eliminate the alchemy from chemistry. Therefore, it was necessary to build a new framework for chemistry and a new nomenclature to eliminate the past.

So controversy allows us to discuss with students the context in which Lavoisier and Priestley lived and worked led them to different ways, to different ideas. Because in the dialog of scientific knowledge with cultural context, theories did not determine the results of experiments, neither experiment determines theories (Hacking, 1983).

To put these arguments in evidence, along with the controversy discussion developed by teacher, the students read, at home, a book (Braga et al, 2000) discussing the controversy and in class they conducted some experimental activities that explicitly the difference between law and theory.

The activities:

1- **Solid expansion.** Doing the experiment the students obtain the law of expansion of solids. But it does not explain why the solid expand. So we discuss the difference between why and how.

2- **Calorimetric experiment.** Doing the experiments the students determined the relevant parameters to determine the heating of a body, but it does not explain what is transmitted between the two bodies. So we use this moment to discuss with the
students that with caloric theory and phlogiston theory was possible to explain what is transmitted between the two bodies.

3- In the discussion students showed some discomfort with the narrative of the controversy. They wanted to know who, Lavoisier or Priestley, built the right theory. When the teacher told that both theory are today considered wrong, and that some name gave by Lavoisier to the chemical elements, like oxygen, had a significance which do not make sense today, the students were impressed with these discussions, they claimed by a truth.

A few students’ comments were:

“experiments should prove which of these two hypotheses was wrong. Scientific knowledge’s based on laws and theories, and theories were accepted by experiments. Rutherford proved his theory about atomic model before set up an experiment to prove it.” (C4)
“the experiments should show which of these two hypotheses is right or wrong” (E34)

4- Given this outcome, after these two activities, and before the controversy narrative end we developed with students two activities that do not have content embedded. We decided to make the aspects of NOS we wanted to discuss with students more explicit.

The first activity was the black box activity; with this activity we discussed the role of models in the scientific knowledge.

With the second activity we put the experimentation in science in scrutiny. The students received a set of wood pieces to build a figure. But with these pieces they could build different figures. So with the same pieces they could build different models, but not any model, because they could not excluded the pieces. The teacher discussed these results and compared them with science experimentation. If the data tell something to scientists, they could not ignore the pieces, but if the data do not answer completely the problem, they have to consider others parameters again.

CONCLUSIONS

After 45 days the students received the four questions that they have answered in the beginning of the course. The results of this survey showed that 62.5 % of students believe that experimentation is a stage of scientific method which confirms the validation of a hypothesis.

“It is the attempt to prove one hypothesis through instruments” (B4).

“It is a fact to be observed in laboratory with a premise, such as the hypothesis test”. (D14)

37,5% of students affirm that the creativity is used only in the building of hypothesis.

“Yes. In the hypothesis elaboration, they use imagination and creativity, and after that they could make the experiments”. (B5)

“Yes, because they use creativity as a starting point, but always based in scientific observations”. (A6)

22.5% the students argued that creativity is part of all scientist’s work. For instance, some of them argue:
“It is something very important, because there are a few obvious things and it is necessary to be open to different opinions “not-so-obvious”. We believe the scientist uses imagination and creativity in all steps, but in some more carefully than others” (A15).

“Yes, in the Project and planning, and after data collection as well. Creativity is needed to create a productive form of data collection and after this data collection to transform the data into ideas. For instance, Galileo turn up the telescope to the sky to visualize something never seen before. Another example is analyzing a ball in movement, it is not only the velocity data collection and its standard deviation, but it is necessary transforming these numbers in an acceleration concept” (E8).

For the difference between law and theory we noted that 27.5% answered the question in the same way that they had answered in the beginning of the course. For this group law is a theory which the scientists had proven with experiments. In the same question, 42.5% argued that theory explain a phenomenon while law describes a phenomenon.

“Yes, when we describe how the things dilate with the variation of temperature we have a law, when we explain this phenomenon with atomic movement we have a theory” (C4).

20% said that law is invariable while theory is variable.

“Theory is an idea accepts by scientists, but always it could be changed. Law could not be changed. Examples: String theory could be change but Gravitation law could not be changed”. (E8)

When we compared the two group of answers and confronted them with the researcher´s notes obtained during the course, we realized that the course have somehow provoked disturbance in the student´s vision of science. In the previous questionnaire the answers were basic without examples that support them. At the end of the survey the answers were more elaborated and the students gave some examples to support their ideas.

In the examples gave by the students something was highlighted for the researchers: 29% of the students who declared that experimentation is a stage of scientific method confirming the validation of a hypothesis used the same example to confirm their ideas. They cited the Brownian movement and the Rutherford experiment as examples to confirm that experimentation is just a way used by scientists to ratify their hypothesis. When we investigated why these groups of students gave the same example, we realized that these were examples that their Physics theory teacher (the one who develops the other three classes) used to prove that the true theory to explain Thermodynamics is the Atomic theory. In an interview with this teacher, he revealed that in beginning of the course he discussed the atomic model, starting by the Greg model and finishing with Rutherford experiment. In his opinion, this is a crucial experiment that confirms the atomic hypotheses. After that, he discussed with the students the Brownian movement and used it like a macroscopic experimentation to prove the existence of a microscope element, the atom.

These results showed us two things. First one the introduction of historical-philosophical issues together with activities that explore some aspects of NOS in scrutiny is a path that leads students to understand the philosophical and cultural implication of science. The historical examples seemed not be sufficient to put science in scrutiny.
It is not easy to discuss NOS. The students have some ideas about NOS that they build throughout their schooling and these ideas are everyday reinforced by teachers. This conclusion does not mean that it is impossible to provoke disturbance in the NOS visions in the students. Our research showed us that the lessons described here were an opportunity for those students to reflect about science. They did not change their vision from a suppose naïve idea to an adequate one but their vision became somehow more complex.

REFERENCES


MISSING LINKS IN THE EXPERIMENTAL WORK: STUDENTS' ACTIONS AND REASONING ON MEASUREMENT AND UNCERTAINTY

Susanne Heinicke\(^1\) und Falk Riess\(^1\)
\(^1\) University of Oldenburg, Germany

Abstract: Over the past 25 years, a number of studies have offered valuable insight into the concepts of students concerning the handling of measurement data and uncertainty. They helped introduce a number of new approaches to the introductory laboratory. However, since most of the studies remain on a theoretical, cognitive level in their method of inquiry and resolution, it seems appropriate to ask: How far have we come to understand and assist students in the problems they face when really conducting an experiment? In our view, this implies not only their acquisition of a theoretical concept but also their understanding of the role of uncertainty in scientific measurement and experimental inquiry in the process of real experimental handling.

To assess this reasoning in action rather than the reasoning on action, 32 students were surveyed in a triangulation study. They were first asked to fill out an online survey about a simple experimental task, EXP1. Subsequently, they were observed by video recording conducting an experiment, EXP2, which was very similar to EXP1, in the laboratory. After the survey and the laboratory task, they were interviewed on their reasoning using the video recordings. We found that reasoning in the survey deviated considerably from that in the laboratory task. An important factor of the students’ difficulties in the second task was due to missing connections between the different aspects of experimental research. These results, which are part of a larger study on students’ reasoning, of the analysis of the corresponding instructive literature and of the historical evolution of the mathematical methods concerned, influenced the design of a model of action-guiding cognitions.

Keywords: measurement, measurement uncertainty, measurement error, experiment, students’ understanding of measurement

BACKGROUND, RATIONALE, FRAMEWORK, AND PURPOSE

Studies of Seré and Larcher (1993), Lubben and Millar (1996), Buffler et al. (2001), Volkwyn et al. (2008), and others, have brought valuable insight into students’ understanding of measurement, especially where the handling of data and calculation of uncertainty are concerned. However, all these studies employed written surveys to assess the students’ notions when discussing a specific (theoretical) action taken in the laboratory. Consequently, we have to raise the question whether these cognitive aspects alone can offer an extensive exploration of the problem. Maisch (2010), for example, indicated that students performed very differently depending on whether they where asked to conduct, design or solely execute an experimental task in the laboratory. It seems therefore reasonable to assume that the differences might be even more apparent when comparing the reasoning given on a theoretical laboratory situation to those that are given and become effective in the conduction of a real laboratory task. (Within the social sciences, the gap between the two concerning everyday life situations has brought forth a whole new branch of research.)
The leading research questions that can be deduced from this are therefore: What notions on the handling of data and their uncertainty can be observed in students’ activities in the laboratory, and how do they correspond to their theoretical arguments on a similar situation? How can this reasoning be described in order to gain further insight into the students’ notions and learning difficulties? What information can be drawn from this to influence the design of a laboratory that includes adequate teaching methods about the nature and the handling of measurement data and uncertainty?

METHODS

In a qualitative study, 32 physics students were surveyed in a three-step methodological design. All students were in their third year of study and thus had concluded one year of intensive laboratory introduction in different fields of physics. As in prior studies, and based on the instrument developed and described by Buffler et al. (2001), the students were first asked to fill in an (online) questionnaire on a mechanical experiment. The questionnaire guided them through different questions and situations requiring decisions in the evolution of a fictional experimental process. We used the same context as Buffler et al. (2001), in which a ball rolls down a (fixed) slope and hits the ground after travelling some distance \( d \), leaving an imprint on the floor. The length of the trajectory here obviously depends on the height \( h \) of the starting point on the slope. All items of the questionnaire (e.g. for the requirement of another reading, the choice of the result of a measurement series or the comparison between different data and data sets) required an assessment of the presented data and especially their uncertainty.

After finding the results of the survey in good agreement with prior studies (e.g. Buffler et al. 2009), we extended the investigation to a practical task. In this second step of the triangulation study, the students were asked to conduct a very similar experiment in a practical laboratory task. The major difference between the two was that the variable parameter was not the height of the effective slope, but its shape that could be formed to different shapes of a curvature. The students conducted the experiment in small groups of two or three. The actions of the students were videotaped but not closely observed by another person in order to establish a situation as similar to the typical first year laboratory as possible.

Following the practical laboratory task, the student groups were questioned on their approach to and proceedings during the task. Clips from the tape recordings were shown during the discussions for mnemonic and transparency reasons. All questionnaires, videos and interviews were evaluated using a content analysis approach, while the latter were also supported by hermeneutic methods in the richer parts of the discussions.

RESULTS

The results of the studies provided a more precise description and understanding of the students’ reasoning on action, as well as valuable insight into the difference between their reasoning on action and reasoning in action as well as the reasons for this divergence.

Description of the students’ notions by means of the Model of action-guiding cognitions

The results of the study showed a sophisticated cognitive analysis of the situation by the students. In almost all cases they were able to give plausible arguments concerning the
notation of results, the number of necessary readings or the routines of data calculation. The discussion of the uncertainty of measurement played only a minor role in their arguments and decision processes. For example, less than a third of the students referred to the limited precision and accuracy of the measurements when comparing different results, or when comparing them with a reference value. The uncertainty of the result in the latter cases was mostly established by estimating the deviation of the result from the reference value. These results confirmed the findings of prior studies by Séré & Larcher (1993), Buffler et al. (2001), Campbell et al. (2001) and Volkwyn et al. (2008) and gave some additional insight as to how the students would assess the accuracy and precision of their data if they did not use the concept of uncertainty. Rather, they employed arguments concerning the numerical values only, different kinds of rules etc. All in all, five different areas of action-guiding cognitions were isolated where students drew their information from in order to answer the questions. Those five areas contained references to either:

- the analysis of the experimental realization,
- the consideration the process of data production,
- the conduction of evaluation procedures,
- the result-based comparisons to a reference value or
- the application of normative rules

These categories gave rise to the model of action-guiding cognitions described above and presented in *Erreur ! Source du renvoi introuvable.* (Four puzzle represent the first four categories and highlight the need of interconnection between them. The fifth forms a framework of formal-normative rules.) The results were also supported by an accompanying study of 151 physics students at German universities who were asked to fill in the online questionnaire as well. This was done to check the results of the triangulation study for (e.g. regional) reliability.

To illustrate the five areas of the model, we can use examples from the questionnaire. For instance, the students were asked to decide and justify whether they would repeat a measurement or leave the result to the one measurement already obtained. In the formal-normative frame focusing on the formal and theoretical aspects of experimental work – like rules, routines and boundary conditions – a typical answer would be: “One always has to conduct any experiment three times.” A result-based argument would rather focus on the obtained numerical result of the measurand, e.g.: “No, my result is close enough to the literature value,” or “I would measure again to check my result.” In contrast, a procedural-evaluative argument would focus on the evaluation routines, e.g.: “I would repeat the measurement to get enough data for the calculations of a mean (and its uncertainty).” In the procedural-productive area, an argument highlights the origin and history of the obtained result: “I would repeat it if I knew that something happened during the previous measurement or if it showed some uncertainties / statistical fluctuations.” Lastly, the area of the experimental design focuses on the significance of the experimental realization: “Probably the electric current will not stay constant all the time, so it would be wise to repeat the measurement a couple of times.”
The model proved helpful in understanding a new aspect of the students’ difficulties in their understanding of the handling of data and measurement uncertainty that had not been elaborated on by former studies. It showed that not only could those different areas be distinguished in the students’ reasoning but also that almost no argumentative links between the different areas were drawn in the students’ answers.

Of course, one might argue that it was not mandatory to cover all or even many of the areas in every argument on measurement data and uncertainty. However, the lack of links between the five areas indicates more extensive difficulties. Those difficulties become more obvious when consulting the further results of the triangulation study. The results show that the missing links between the five areas run deep not only in the situative argumentation but in the students’ understanding of the matter.

**Comparison of reasoning on action and reasoning in action: missing links**

The results of the second part of the study were thus quite unexpected. While all but three of the 32 students had argued in the written survey that the experiment had to be conducted more than once, the practical task showed distinctly different results. Only four out of 13 groups actually conducted a reading of the same shape of the curvature more than once. Even more surprising was that in none of these four cases this approach was heralded by any discussion on the experimental set-up, on the expected data fluctuations or even general remarks on experimental methods, let alone measurement uncertainty. Of those four groups, one decided on a threefold repetition due to some rule that “you always conduct three runs” and the repetitions of the other three merely happened by chance, e.g. because the experimenters could not agree on the result of the first run and decided to take another roll – only to notice that the second roll agreed with neither of their expectations. Just the same, the discussion of uncertainty played yet a minor role in most of the written surveys, however, in some or the other form it appeared in about half. On the contrary, none of the 13 groups observed discussed any aspect on the uncertainty of the data collected.

Protocols of the real experimental task in the triangulation show that in some cases the students had all relevant information of the different areas at hand, yet failed to put them together into a coherent picture. (That is why the design of the model was chosen as a puzzle.) In group 3, for instance, one student commented on the experimental design (which was purposely designed to be very unstable): “The belt [adjusting the curvature] is always slipping off.” They also realized that the experimental process failed to produce stable results and employed different rules of thumb on the data production and evaluation processes. Yet, when one student suggested repeating one of the measurements for the same shape of the curvature, the other two could not see any reason for it. Moreover, they all predicted the repetition measurement would reproduce the results already obtained during the second check-up, e.g. stating: „I hope it will come out the same!“ At the end, with all information close at hand, yet failing to piece it all together, they were completely puzzled: „Okay – I really wonder why that happened just now.“ – „Me too – beats me.“

Further factors we could determine as influential on the students’ practical performance concerned their personal or emotional state of mind. One group, for example, was unable to deepen their rudimental insight into the difficulties of the situation because one of them showed a very low frustration tolerance, causing her partner to become very anxious to present ad hoc solutions without subjecting the thought-provoking impulses to close scrutiny. They thus failed to come to the heart of the problem and discuss the uncertainty involved, as the first student was too easily frustrated and the second too eager to keep her in good spirits. Other important factors mentioned by the students in the follow-up interviews concerned the pressure they felt in a common laboratory task like this one to come up with a proper
CONCLUSIONS AND IMPLICATIONATIONS

Our study concludes that there are many more factors apart from the cognitive ones that influence students’ notions on the handling of measurement data and their uncertainty. In our view, those factors are closely related to the way in which we present the experiments in the introductory laboratory and the teaching of physics. The experimental tasks often contain a closed question, they are mostly context-independent and design-free, i.e. the aspired results are often known a priori and the tasks commonly do not illustrate a scientific problem but a surgically separated phenomenon. The experimental set-up in most cases is given within the texts and does not allow for or even stimulate any enhancements by the students. As the representation of students’ notions by the model of action guiding cognitions show, the links between the areas are often missing, resulting in a poor apprehension of the complex experimental situation in a real laboratory task. Laboratory tasks and especially laboratory introductions to the handling of measurement data and uncertainty should therefore emphasize those links and support students to construct a coherent and complex understanding of the experimental situation. So far, introductions to data analysis in textbooks and in the teaching of physics are most likely to resemble a surgical simplification of the problem and promote rules of thumb that are not rooted in the consideration of the experimental set-up or situation at hand. Given the results of our study, future developments of the physics laboratory should take those factors into account – not only to aim at the transfer of experimental routines, but also at a sound understanding of the connection between different aspects of experimentation. As Buffler et al. (2009) point out, these connections are just as relevant when it comes to the understanding of the nature and the handling of measurement data and their uncertainties.

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KEY TEACHER’S ROLES IN SUPPORTING THE CO-CONSTRUCTION OF STUDENTS’ KNOWLEDGE IN MODELLING-BASED TEACHING CONTEXTS

Rosária Justi, Paula Paganini Costa and Nilmara Braga Mozzer

1Education Post-graduation Programme, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

Abstract: Modelling is a key process in the development of scientific knowledge. In order to conduct a more authentic science education, it is advocated that it should be conducted from a modelling-based perspective. However, the conduction of modelling-based activities in a way that really results in students’ learning is not an ordinary task for teachers (who, in general, do neither discuss such a teaching approach in their education process nor experience it as students). In this paper, some data from a modelling-based teaching of solubility which occurred in a regular classroom in Brazil are analysed aiming at discussing the following research question: What are the key teacher’s roles in supporting the co-construction of students’ knowledge in a modelling-based teaching context? From such a discussion, relevant implications and recommendations for science teachers interested in based their practice in a modelling approach are also proposed.

Keywords: modelling-based teaching, co-construction process, teacher’s role.

INTRODUCTION

Modelling in Science Teaching

There has been a general agreement that science education must be closer in terms of process to the practice of science (Gilbert, 2004). As modelling is one of the essential processes in producing, validating, and disseminating scientific knowledge (Gilbert, Boulter, & Elmer, 2000), some science education researchers (for instance, Boulter & Gilbert, 2000; Clement & Rea-Ramirez, 2008) have emphasised the importance of model-based teaching and learning as a way to stimulate scientific understanding. This is so because such a teaching approach fosters students not only to create their own models, but also to assess their models, those produced by their colleagues, and those introduced by the teacher. As an outcome of this process, they can build their knowledge from the establishment of relationships between multiple ideas, as well as understand modelling and its role in the development of scientific knowledge. Therefore, modelling-based teaching also contributes to actively engage students in their learning process, as well as in doing and thinking about science.

In one of the first attempts to shed light on the process of learning via model construction, Clement had proposed a Model Construction Cycle that represents a cyclical process of hypothesis generation, rational and empirical testing, and modification or rejection of a model (Clement, 1989). According to him, such stages were experienced by scientists, but could have relevant implications in science education if the cycle could be used to describe the process that students should experience when learning scientific models. Thus, he claimed the Model Construction Cycle should be used as a basis for designing instructional activities aiming at promoting the learning of scientific models.

In a more recent publication, Clement (2008b) presented a new version of this cycle renamed GEM cycle (model generation, evaluation, and modification). Then, students’ learning process was described as constituted by three main aspects: students’ initial ideas
that base their first model; an evolutionary sequence of models and revisions; and discrepant questions or events that provide scaffolding which enable students to modify their models. This last aspect involves an interaction where the teacher and the students work together to construct and evaluate mental models of a target concept, which Clement named *teacher-student co-construction*.

By analysing what philosophers of science say about how scientific knowledge develops (Nersessian, 1999; Vosniadou, 2002), as well as the work of scientists who have significantly contributed to such a development, Justi and Gilbert (2002) identified some elements and organised them in a diagram (named Model of Modelling) that favours the discussion of how scientists perform the modelling process. It was also inspired by Clement’s Model Construction Cycle, but tried to complement it by either introducing new elements or making additional relationships between all their elements explicit. According to it, modelling is comprised of four stages: *elaboration of the initial mental model; expression of the mental model* by using any of the modes of representation (concrete, visual, verbal, virtual, mathematical, and gestural); *tests of the expressed model* through mental and/or empirical experimentation; and *evaluation of the final consensus model*, that is, the identification of the scope and limitations of the model, which occurs from both contrasting the model with its aims and trying to use it in distinct contexts.

In the last years, our research group have been investigating modelling-based teaching from the ‘Model of Modelling’ diagram perspective. We have developed teaching sequences comprised of several related activities for a series of chemical topics, which have been applied in regular classes. By participating in these activities, students are involved in all these stages in order to build their knowledge. The use of such activities characterise a socio-interactive constructivist teaching context (Vygotsky, 1986) in which knowledge build occurs from student-student and student-teacher interactions. We recognise that, in specific moments of the process, it is essential that the teacher interact with students in order to favour and foster their engagement in the process. When such an interaction results in students’ learning, we say that teacher-student co-construction occurs.

### Teachers’ action in modelling-based teaching

Some of the main necessary conditions for the occurrence of students’ learning are the teacher’s own competence in models and modelling, and his/her pedagogical content knowledge (PCK) on this area (Justi & Gilbert, 2002; Justi & van Driel, 2005; Núñez-Oviedo & Clement, 2008). However, previous attempts to characterise such knowledge (Crawford & Cullin, 2004; van Driel & Verloop, 1999) showed that teachers’ practices rarely include modelling activities, mainly because they are not competent in this area.

Teachers’ PCK related to the conduction of modelling-based activities are different from those involved in ordinary traditional teaching situations. This is so mainly due to the complexity of both the modelling process itself, expressed, for instance, by the dynamic and non-linear relationships in each stage and between different stages, as well as by the conduction of the mediating process.

Some previous studies (Justi, Chamizo, Franco, & Figueirêdo, 2011; Justi & van Driel, 2005) have shown that teacher’s PCK on modelling include comprehensive elements like their: general view on modelling-based teaching; knowledge and skills required for producing modelling-based teaching activities; knowledge and skills required for conducting modelling-based activities; general view about how students reason and build their knowledge when participating in modelling-based activities; and knowledge and skills for accessing students’ knowledge and skills developed in such a context. Therefore, in order to support teachers’ education from this perspective, it is necessary to deeply investigate each of these elements of teacher’s PCK.
RESEARCH QUESTION

In this paper, part of the results of an investigation conducted in a modelling-based teaching context is discussed. In particularly, it focuses on one aspect of teachers’ knowledge and skills concerning the conduction of modelling-based activities: their actions in favouring knowledge co-construction. The following research question is addressed: What are the key teacher’s roles in supporting the co-construction of students’ knowledge in a modelling-based teaching context?

METHODOLOGICAL ASPECTS

Context and Sample

A set of modelling-based activities was developed from the Model of Modelling diagram perspective to support the teaching of qualitative aspects concerning solubility to 15-16 year-old students (Mozzer & Justi, 2009). In such a teaching sequence, students are asked to express their mental models by using two modes of representation: concrete mode and analogies. Students perform the activities in groups. During the group discussions, sometimes they also interact with the teacher in order to discuss their doubts or asking his/her questions about the content of their discussions, the codes of representation they used in producing the concrete model, and the aspects of their analogies that has not been clearly expressed. Moreover, after each activity, the teacher conducts a class discussion in which each group presents its ideas/models, justifies them, and answers colleagues’ questions about them. It is exactly in the context of such discussions that the co-construction occurs. Therefore, the discussions do not aim at correcting students’ models. Rather, they aim at (i) discussing the coherence of the models in the light of both the available information and students’ previous knowledge, and (ii) favouring students’ own questioning about the proposed models.

Such activities were applied in a regular class comprised of 36 students in the last month of the academic year. They had already studied properties of substances and chemical bonding around 8 months before, but from a traditional approach. As far as our data showed, they had several improper conceptions about both topics and none of them showed any previous acceptable understanding about how a substance dissolves into another. Moreover, they had previous experience with neither modelling-based activities nor investigative experimental activities. In all lessons, students have worked in groups comprised of 5-6 students.

The chemistry teacher guided the whole process. As she had no previous experience with modelling-based teaching, before the starting of the study, the third author met her twice. In such meetings, they discussed about the teaching context, the students’ previous ideas related to the topic, the modelling-based teaching from the Model of Modelling diagram perspective, students’ drawing of analogies, the relationships between analogies and models, and the conduction of the modelling activities. So, these meetings were essential in order to improve the teacher’s understanding on both the modelling-based teaching process and the purpose of our study. The teacher has participated in both the meetings and the lessons with great enthusiasm.

Data Collection

All lessons were video-recorded. The videos focused on the discussion between the students in their original groups and those between the students and the teacher. All the moments when the teacher interacted with a given group of students (for which we were able to record most of the discussions) were transcribed verbatim.
Data analysis

In analysing the transcription, we have identified specific moments in which co-construction occurred. A deeper analysis of such moments made it possible to classify all the teacher’s actions in terms of their function in the co-construction process. This was done independently by all authors and some disagreements were discussed until they were solved. Then, such categorisation was used to support the discussion of the research question.

RESULTS

The main teacher’s roles in supporting the co-construction of students’ knowledge in modelling-based teaching contexts could be organised into five groups of actions. They are presented in no specific order.

Group 1: Organisational actions.

Although they were important in all teaching activities, they have to be emphasised in modelling-based ones because, in such a context, they aimed at favouring the participation of the students in the activities and the expression of their ideas – elements that are essential for the occurrence of co-construction.

For instance, during Activity 2, when one of the groups was producing a model to explain the dissolving of the powder juice in water, one student, who seemed to be a leader in the group, said:

\[ I \text{ think the juice and the water mixed with each other due to the ‘natural’ movement of water. } (S1) \]

Apparently, his colleagues have agreed with him, and continued discussing macroscopic characteristics of the system related to the intensity of the colour. Some minutes later, the teacher, who was following the discussion, asked the whole group:

\[ \text{Do you agree with him about the role of the water ‘natural’ movement?} \]

Although hesitating, one of them said:

\[ \text{There may be something more because... why don’t the particles go down in a while? } (S2) \]

The discussion continued and the teacher continued to provide an incentive for all the students to participate in the discussion, which was essential for encouraging them to express their ideas. This resulted in a significant improvement on their model, as well as in making them think about the relationship between the macro system and a sub-micro model that could explain its behaviour.

Group 2: Actions that favour the expression and discussion of students’ codes of representation.

Such actions always occurred when students produced concrete models, and they were motivated by two specific reasons: when the teacher has realised a given code of representation might be associated with students’ misconceptions, and when the ideas represented in a model were not clear.

Moreover, when students produced analogical models, the teacher has asked them about the similarities between the compared domains. In some sense, this means to ask about codes of representation because students could explain the structural basis of their representations. For instance, group 2 compared the chalk system with the class in different environments. According to them,
It could be the class in the classroom and here, in the laboratory. Here, each group is like a grain of chalk and the groups are not so close to each other. In the classroom the students, like the chalk particles, were closer to each other. Here, in the lab, we are separated in groups, and in each group a given number of students is kept together.

When explaining the similarities between the two domains, the students were able to clearly express how they were visualizing the sub-microscopic aspects of the system. As the ability to move fluently between the three levels of representation (the macroscopic, the symbolic, and the sub-microscopic ones) is essential to foster a full understanding of chemical phenomena (Gilbert, 2005), questions concerning students’ views on the relationships between them tends to favour students’ knowledge construction.

**Group 3: Actions that favour the expression and discussion of students’ previous ideas.**

Students’ previous ideas are essential to support the building of their initial models and, sometimes, the testing of them. However, very often they do not remember adequate previous ideas, that is, those that may be related to the context in discussion. Other times, it seems that they try to guess without reflecting on their answers. In both cases, teachers’ questions about the meaning of such ideas may help students to critically analyse them. For instance, one of the students said both phenomena (water + piece of chalk, and water + powder grape juice) could be explained by the density of the materials. Then, the following dialogue occurred:

T: *Which one is denser: the piece of chalk or the water?*
S5: *The piece of chalk.*
T: *And which one is denser: the powder juice or the water?*
S5: *It should be the powder juice because it sank.*
T: *And what did happen with the piece of chalk?*
S5: *It did not dissolve.*
T: *And with the juice?*
S5: *It dissolved.*
T: *So, how does density explain the phenomena?*
S5: *It doesn’t explain. There should be something that is different from one system to another...*

Here, the teachers’ questions made the student analyse the phenomena based in his previous ideas. This supported his following conclusions: (i) his ideas were not adequate to explain them, and (ii) the phenomena were not caused by a given characteristic of the material introduced into water, but by a characteristic of the system (that is, something related to the material and the water).

**Group 4: Actions that favour the expression and discussion of students’ understanding of empirical evidence.**

In Activity 3, when students mixed the powder grape juice in water without stirring the system, many of them have showed to be confused by the sequential observations related to the slowly dissolving of the powder juice. Then, the teacher asked them to conduct the experiment again, and questioned each of their expressed observations or comments. This resulted in students using the empirical evidence as sources of information for testing their previous model and producing a new one.
Group 5: Actions that favour the expression and discussion of students’ current ideas and models.

Such actions were very common when the teacher interacted with each group and, mainly, when she conducted the final discussions in each activity, that is, when she coordinated the presentation of each group’s model to the whole class and the following discussions (when students from different groups argued with each other about their models). In such moments, the teacher has not put the ideas of one student directly against those of other students. On the contrary, she has tried to favour the expression, detail, and justification of each student’s ideas. This also resulted in more interactions between the students. From them, students could establish new relationships between their ideas, thus constructing their knowledge.

CONCLUSIONS

In this study, we have identified five groups of teacher’s roles that support the co-construction of students’ knowledge in a modelling-based teaching context: organisational actions, actions that favour the expression and discussion of students’ codes of representation, previous ideas, understanding of empirical evidence, and current ideas and models. This evidences that the teacher’s roles go beyond the use of discrepant questions (Rea-Ramirez & Núñez-Oviedo, 2008) or promoting “students to contribute to a discussion with ideas that are contradictory to each other” (Núñez-Oviedo & Clement, 2008, p. 117), as it was proposed in some previous studies. On the contrary, this identification and the analysis of the complexity involved in some situations in which they occur highlight the importance of teachers mediating the learning process, but simultaneously giving students the chance to act in the process. Moreover, teachers should pay special attention in order to identify moments where it is essential to change the focus of a given discussion or to foster students’ thinking in a different level (which is particularly important in chemistry teaching because students tend to keep the discussion into the macroscopic level).

Therefore, teachers’ educational process should include opportunities for understanding the importance of their actions that can favour the co-construction of students knowledge in modelling-based teaching contexts, developing the knowledge that support such actions, and practicing them. This seems to be a great challenge for science teachers’ educators due not only to the complexity of the knowledge characterised in the previous paragraph, but also to the general inexperience of teachers in modelling. However, we believe the characterisation of teachers’ actions we presented here can support the proposition of specific activities that may foster the development of teachers’ PCK on modelling.

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FORMAL ANALOGIES IN PHYSICS TEACHER EDUCATION

Ricardo Karam and Elio Carlos Ricardo
School of Education, University of São Paulo, Brazil

Abstract: Reasoning by similarities, especially the ones associated with formal aspects, is one of the most valuable sources for the development of physical theories. The essential role of formal analogies in science can be highlighted by the fact that several equations for different physical situations have the exact same appearance. Coulomb’s law’s similarity with Newton’s, Maxwell’s application of fluid theory to electromagnetism and Hamilton’s optical-mechanical analogy are some among many other examples. These cases illustrate the power of mathematics in providing unifying structures for physics. Despite the relevance of the subject, formal analogies are rarely systematically approached in physics education. In order to discuss this issue with pre-service physics teachers, we planned a lecture and designed a questionnaire with the goal of encouraging them to think about some “coincidences” in well-known formulas and to give reasonable justifications. The details of this activity and its main results will be presented. Overall, the outcomes show that although the participants already knew each one of the given formulas, the majority of students were not able to identify deeper similarities between them. The analysis of the students’ answers to the questionnaires and to the questions posed during semi-structured interviews allows us to propose a set of categories (levels) to classify the quality of analogy perception.

Keywords: Formal analogies in physics, Analogy perception, Pre-service physics teacher education

IMPORTANCE OF ANALOGIES IN PHYSICS

And I cherish more than anything else the Analogies, my most trustworthy masters (Kepler, quoted in Polya, 1954, p. 12).

Reasoning by similarities (analogy) is one of the greatest sources for the development of physical theories. The essential role of analogies in science can be highlighted by several historical examples: Rutherford’s planetary model of the atom, Coulomb’s law’s similarity with Newton’s, Carnot’s comparison of heat engines with waterfalls, Thomson’s analogy between heat and electricity, Maxwell’s application of fluid theory to electromagnetism and Hamilton’s optical-mechanical analogy are some among many others. In its essence, analogy is similarity on a more conceptual level, since it is strictly dependent on the intentions of the thinker (Polya, 1954). According to Gentner (2002), the “basic intuition behind analogical reasoning is that when there are substantial parallels across different situations, there are likely to be further parallels” (Gentner, 2002, p. 106). In this sense, analogical arguments can be used to generalize concepts, theories and methods so that they “become applicable to classes of objects which are not of the same kind as those to which they originally apply” (Tzanakis, 1998, p. 69).

Among the broad variety of theoretical frameworks in this field (Vosniadou & Ortony, 1989), we are particularly interested in analogies that are represented mathematically. For that reason, we consider the differentiation between material and formal analogy proposed by Hesse (1972). According to her, material analogies are taken into account when there is a physical similarity between the systems - treating a gas as a set of tiny spheres for example - whereas formal analogies occur when the same axiomatic and deductive relations associate
both subjects and objects of similar systems, without the necessity of a material similarity between them - e.g., a RLC circuit and a spring-mass system. In this last example two considerably different physical phenomena are represented by the same differential equation and, by focusing on correspondent terms, it is possible to make promising associations such as considering the inductance as the “mass” of the circuit. The distinction between these two types of analogies is not trivial, but Hesse stresses that although two systems may have only formal analogy, the contrary does not seem to be possible since “if there is material analogy, there is presumably some structural similarity that could - at least in principle - be formalized” (Hesse, 1972, p. 355).

Raising attention to the role of formal analogies in physics, Pask (2003) states that “many powerful analogies are those in which the mathematical description component is central” (Pask, 2003, p. 526). As a historical example the author holds that the wave theory success is related to the fact that “Fresnel expressed the analogy between light and other waves in mathematical form and so overcame the mechanism difficulties involved” (p. 529). When it comes to analyzing more recent theories of the contemporary physics, the role of formal analogies becomes even more fundamental. According to Steiner (1998), the only alternative scientists found to overcome the human incapability of reasoning about objects out of our daily life and arrive at the subatomic laws of nature was mathematical analogy. Through an extensive analysis of the cardinal discoveries of contemporary physics, the author emphasizes the methodological change that took place in the last century due to the physicists’ use of Pythagorean analogies - “the ones inexpressible in any other language other than pure mathematics” (Steiner, 1998, p. 3). In fact, the unifying character of formal analogies is one of Feynman’s arguments to justify why, despite the enormous amount of information acquired since the beginning of scientific progress, it is actually possible for a physicist to retain a considerably broad knowledge of the physical world:

*The equations for many different physical situations have exactly the same appearance.* Of course, the symbols may be different but the mathematical form of the equations is the same. This means that having studied one subject, we immediately have a great deal of direct and precise knowledge about the solutions of the equations of another (Feynman, 1964, p. 12-1).

**ANALOGICAL REASONING IN PHYSICS EDUCATION**

Due to the outlined indispensable role of formal analogies in physics, we strongly believe that they should be approached in physics education. However, one must be aware of the complexity of the theme, since perceiving analogies frequently demands a more expert-like relation to the physical knowledge. In this sense, it is not easy to envisage this approach in secondary school level. Perhaps a promising strategy is to encourage students to think about the reasons for the similarities in some physical formulas they learn. Let us consider the following three equations: \( x = x_0 + vt, \) \( v = v_0 + at \) and \( p_2 = p_1 + \rho gh. \) It should not be difficult to bring to light the unifying mathematical structure (final = initial + variation) common to all three equations.

An interesting proposal designed for high-school, which is grounded in formal analogies, is the Karlsruhe Physics Course (Herrmann, 2000). Adopting the intuitive “substance model”, in which substance-like quantities have their balance governed by the differential equation \( \frac{dX}{dt} = I_X + \Sigma X \) (where \( X \) is the amount of substance, \( I_X \) is a current intensity of \( X \) and \( \Sigma X \) is the production rate of \( X \)), this framework enables the establishment of associations between different physical extensive quantities, like electric charge, momentum, entropy and amount of substance. Arguing in favor of a meaningful unified approach to science teaching, the author stresses that “when using the extensive quantities as a basis for structuring the course,
one can take advantage of a far-reaching analogy between the various parts of physics” (Herrmann, 2000, p. 52).

**STUDY DESIGN: SEARCHING FOR “HIDDEN SIMILARITIES”**

Aiming at approaching this theme in physics education, we have conducted a study that involved planning a lecture, designing a questionnaire and conducting semi-structured interviews with the goal of discussing the role of formal analogies with pre-service physics teacher students from the University of São Paulo in Brazil. The questionnaire was designed to encourage them to think about some “coincidences” in well-known physical formulas and demand reasonable explanations. We are mainly interested at the following questions: i) Are the students’ capable of recognizing formal analogies? ii) How can the level of this recognition be categorized?

The 4-hour lecture was divided into two parts: the first two hours were dedicated to the discussion of an introductory text (Karam, 2007) on the role of mathematics in physics in which some historical examples and implications for education are presented. Afterwards, the 24 students answered the questionnaire and a final group discussion was coordinated by the lecturer.

In this work we present and describe the analysis of the following question: Consider the equations \( y = \frac{gt^2}{2}, \quad K = \frac{mv^2}{2}, \quad U_e = \frac{kx^2}{2}, \quad W = \frac{CV^2}{2} \). Comparing their mathematical structure, try to give reasons for the formal similarity between them. Is it possible to establish some correspondence between their terms? Stress not only similarities, but also differences. This question was part of the questionnaire and was more deeply approached during the semi-structured interviews with four students.

**RESULTS: QUALITY OF ANALOGY PERCEPTION**

There are several possibilities of establishing analogical relations between the four equations given by the task, from the simple recognition of the integral of a linear relation until the unifying concepts of energy and work. The greater the number of associations perceived the better the quality of the analogy perception. The following table summarizes some possibilities.

<table>
<thead>
<tr>
<th>Constants</th>
<th>Linear relations</th>
<th>Infinitesimals</th>
<th>Integral</th>
<th>Work of a force</th>
<th>Conservative field</th>
</tr>
</thead>
<tbody>
<tr>
<td>( g )</td>
<td>( v = gt )</td>
<td>( dy = vdt )</td>
<td>( y = \int_0^t gt , dt )</td>
<td>Moving force</td>
<td>Gravitational field</td>
</tr>
<tr>
<td>( m )</td>
<td>( P = mv )</td>
<td>( Fdx = v , dm )</td>
<td>( K = \int_0^v v \cdot d(mv) )</td>
<td>Elastic force</td>
<td>“Elastic” field</td>
</tr>
<tr>
<td>( k )</td>
<td>( F = -kx )</td>
<td>( dU = -Fdx )</td>
<td>( U_e = -\int_0^x -kx , dx )</td>
<td>Electric force</td>
<td>Electric field</td>
</tr>
<tr>
<td>( c )</td>
<td>( Q = CV )</td>
<td>( dq = CdV )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Possible associations between the four equations.

The 24 students who participated in our study performed rather badly on the analogy perception task. The analysis of their answers to the questionnaire, as well as semi-structured interviews conducted with four students, led us to the identification of four levels of analogy perception, which are described and exemplified in the following:

**Level I – Superficial recognition of evident similarities (79.2%)**
Superficial similarities are recognized, but neither physical justifications nor formal deductions are given.

Analyzed task: students only notice that all formulas consist of a constant multiplied by a squared variable.

Transcripts: “because in all cases we have a constant divided by two and a squared variable”; “the mathematical structure of the equations is similar. All of them have the general form \( y = a.x^2 \) and can be represented by a parabola”.

**Level II – Focus on formal deductions – lack of physical concepts (12.5%)**

The justification is based on formal arguments and mathematical deductions. However, no physical unifying concept is mentioned and the physical understanding of the mathematical formalism is deficient.

Analyzed task: students mention that all formulas come from the integral of a linear function, but don’t make correlations with physical concepts like energy, work or field.

Transcript: “All formulas can be derived from the integral over the independent variable. E.g. \( y = \frac{1}{2} gT^2 \).”

**Level III – Focus on physical concepts – lack of formal deductions (Questionnaire: 8.3%)**

Physical concepts are mentioned, qualitative explanations for the similarities are given, but no mathematical deduction is given.

Analyzed task: students mention the relation of some formulas with the physical concepts like energy, work or field, but don’t recognize deeper formal similarities.

Transcript: “In order to obtain these equations it is necessary to evoke the physical concepts of work and energy. Since these concepts are mathematically represented in similar ways, the equations have the same mathematical structure”.

**Level IV – Coherent combination of physical concepts and formal deductions**

Full comprehension of the analogy. Physical concepts are coherently connected with mathematical deductions. Physical-mathematical understanding.

Analyzed task: students should mention the relation of some formulas with the physical concepts like energy, work or field and recognize deeper formal similarities (Table 1).

No student was classified in this level.

**CONCLUSIONS**

In spite of the relevance of the subject, formal analogies are rarely systematically approached in physics education. In this sense, our preliminary results are actually not surprising. Although the students have already studied each one of these formulas separately, it is likely that they were seldom encouraged to think about these similarities and to find the unifying mathematical structure behind them. Therefore, we strongly believe that an explicit approach of the role of formal analogies with the pre-service physics teachers should enhance the quality of their perception of this valuable reasoning for physics.

Following Feynman’s citation, reasoning by formal analogies is an essential physical trait and therefore should be part of the physics teacher training curriculum. Additionally, we
believe that it can facilitate students’ awareness of the structural role of mathematics in physical thought (Uhden, Karam, Pietrocola & Pospiech, 2011). Thus, it is also related to the introduction of Nature of Science (NOS) discussions in science teachers training courses, which has been widely recommended by the literature (Abd-El-Khalick & Lederman, 2000).

REFERENCES


ASSESSMENT OF STUDENTS’ CONCEPTS OF MODELS AND MODELING: EMPIRICAL EVALUATION OF A MODEL OF MODEL COMPETENCE

Moritz Krell\textsuperscript{1}, Annette Upmeier zu Belzen\textsuperscript{2}, & Dirk Krüger\textsuperscript{1}
\textsuperscript{1}Freie Universität Berlin, Department of Biology Education
\textsuperscript{2}Humboldt Universität zu Berlin, Department of Biology Education

Abstract: Models and the modeling process are important both for scientific inquiry and communication as well as for teaching science. Several studies have described different perspectives of thinking about models. Often, different levels of understanding are either assumed or developed empirically. These levels either can be general, without differences between various perspectives, or they can be specific due to the different perspectives. This means that there are differences in the level of understanding between distinct perspectives. In the present article, a theoretical structure of the understanding and handling of models is presented which is called the model of model competence. In this structure, five perspectives are described, each with three levels with an increasing rate of understanding. Forced choice-tasks were used to assess the students’ understanding of models and modeling according to the model of model competence (N = 1,180, aged 13-16). The data was used to address the issue of levels of understanding and handling models. The results indicate that there are no general levels of understanding models and modeling but five distinct perspectives.

Keywords: models and modeling, level of understanding, forced choice-tasks

INTRODUCTION

The importance of models and the modeling practice for scientific inquiry has been well described. For example, models support the development of scientific theories, they allow for the description and interpretation of data and they are promoting creative insight and imagination (cf. Frigg & Hartmann, 2006). Therefore, models are seen as “effective pedagogical tools” (Halloun, 2007, p. 653) for teaching scientific literacy. Because of these advantages, Harrison and Treagust (2000) point out that models are central for teaching and learning science.

The facilitation of a competent understanding and handling of models needs an elaboration of the perspectives that are related to the understanding of models and modeling. Due to diagnostic reasons, it is helpful to describe levels with an increasing grade of competence, too (cf. Hartig, Klieme, & Leutner, 2008). However, it is not clearly investigated whether such levels should be seen as general or as specific to the respective perspectives (cf. Grosslight, Unger, Jay, & Smith, 1991; Justi & Gilbert, 2003; Crawford & Cullin, 2005; Terzer, Krell, Krüger, & Upmeier zu Belzen 2011). In the following, the levels are called general when the level of understanding is equal in all perspectives. In this case, there is an understanding of models and modeling “as a whole” (Grosslight et al., 1991, p. 817) and the perspectives are not empirically distinguishable. If the level of understanding differs across distinct perspectives, it can be called specific (to the perspectives). In the present article, a theoretical structure of the understanding and handling of models developed by Upmeier zu Belzen and Krüger (2010) is presented which is called the model of model competence. In this structure, five perspectives are described, each with three levels with an increasing rate of understanding. Forced choice-tasks were used to assess the students’ understanding of models...
and modeling according to the model of model competence. The data was analyzed to address
the issue of general levels of understanding and handling models. Talking in terms of school
practice, this can be used to decide whether to reflect on different perspectives separately or to
discuss models and the modeling process as a whole (cf. Justi & Gilbert, 2003).

THEORETICAL BACKGROUND

A Model of Model Competence for Biology Education

Primarily based on the studies of Grosslight et al. (1991), Justi and Gilbert (2003) as well as
Crawford and Cullin (2005), Upmeier zu Belzen and Krüger (2010) worked out a theoretical
structure in which two broad perspectives (dimensions) of the understanding and handling of
models are described (Table 1): knowledge about models and the modeling process
(modeling). Whereas the first dimension is subdivided into the two aspects nature of models
and multiple models, the second dimension entails the aspects purpose of models, testing
models and changing models. Each aspect is further divided into three levels of understanding
based on the concept of model described by Mahr (2009). The author underlines that the
identity of something as a model depends on two “constructive relationships” (p. 371): an
object is a model as long as it is a model of something (creation of the model) and a model for
something (application of the model). Mahr also distinguishes between the model object
which can have different modes of representation such as concrete material, visual, or verbal
(cf. Boulter & Buckley, 2000) and the model which is “purely mental” (Mahr, 2009, p. 371). Thus,
it is possible to understand a model only as a model object without recognizing the
connection with the corresponding mental model. This concept of a model was used by
Upmeier zu Belzen and Krüger (2010) to develop the three levels of understanding in the
model of model competence (Table 1). However, the theoretical structure has not been
evaluated empirically yet.

Table 1: A model of model competence (Upmeier zu Belzen & Krüger, 2010).

<table>
<thead>
<tr>
<th></th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knowledge about models</strong></td>
<td>Replication of the original</td>
<td>Idealized representation of the original</td>
<td>Theoretical reconstruction of the original</td>
</tr>
<tr>
<td><strong>Nature of models</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multiple models</strong></td>
<td>Different model objects</td>
<td>Different foci on the original</td>
<td>Different hypotheses about the original</td>
</tr>
<tr>
<td><strong>Modeling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Purpose of models</strong></td>
<td>Describing the original</td>
<td>Explaining the original</td>
<td>Predicting something about the original</td>
</tr>
<tr>
<td><strong>Testing models</strong></td>
<td>Testing the model object</td>
<td>Parallelize the model and the original</td>
<td>Testing hypotheses about the original</td>
</tr>
<tr>
<td><strong>Changing models</strong></td>
<td>Correcting defects of the model object</td>
<td>Revise due to new insights</td>
<td>Revise due to the falsification of hypotheses about the original</td>
</tr>
</tbody>
</table>

Levels of Understanding Models and Modeling: General or Specific?

There are several studies in which the students’ (e.g. Grosslight et al., 1991; Grünkorn,
Upmeier zu Belzen, & Krüger, in press; Treagust, Chittleborough, & Mamiala, 2004) or the
teachers’ (e.g. Justi & Gilbert, 2003; Crawford & Cullin, 2004, 2005) understanding of
models and modeling is investigated. In the following, three of these are introduced which address the levels of understanding.

One of the first studies about the understanding of models is presented by Grosslight et al. (1991). According to the authors there are mainly five different perspectives (called aspects) in the understanding of models and modeling (kinds of models, purpose of models, designing and creating models, changing models and multiple models). Furthermore, the authors were able to describe three “general levels of thinking about models” which describe the “understandings and conceptions of models […] as a whole” (p. 817). Justi and Gilbert (2003) asked teachers about models and worked out seven aspects which are similar but not identical to the ones described above: nature of models, use of models, entities of which the models are composed, uniqueness of models, stability over time, making predictions and accreditation of models. Justi and Gilbert (2003) explicitly address the question of general levels in their analysis and conclude that “data provide no support for the notion of ‘level’ in the teachers' understanding of the notion of ‘model’” (p. 1381). In fact, most of the interviewed teachers show a complex pattern of understanding which varies across the different aspects (Justi & Gilbert, 2003). A third study which deals with levels of understanding models and modeling is presented by Crawford and Cullin (2004, 2005) who interviewed prospective teachers. The authors report five dimensions which are similar to the aspects described by Grosslight et al. (1991): purpose of models, designing and creating models, changing a model, multiple models and validating and testing models. In addition, the authors assumed four general levels of understanding: limited, pre-scientific, emerging scientific and scientific. Although Crawford and Cullin (2005) were able to report a shift in the teachers’ understanding, their subjects “tenaciously held on to some scientifically uninformed views” (p. 318).

In sum, these studies give an ambiguous answer to the question whether there are general levels in the understanding of models and modeling or not. Whereas Grosslight et al. (1991) report general levels, both Justi and Gilbert (2003) and Crawford and Cullin (2004, 2005) are not able to identify general levels of understanding across the different aspects. In other words, it is not clearly investigated whether there is an understanding of models and modeling as a whole or if the level of understanding varies between different distinct perspectives. The present article addresses this issue related to a theoretically developed structure of understanding and handling models which is called the model of model competence (Table 1).

**RESEARCH QUESTION AND HYPOTHESES**

The research question of the study is related to the empirical evaluation of the model of model competence: In what sense are the three levels of understanding general or specific to the respective aspect? Three alternative hypotheses (H1, H2, H3) can be deduced from the theory:

H1: The three levels are general. The level of understanding does not vary between the different aspects.

H2: The three levels are partly general. The level of understanding does not vary within the two dimensions knowledge about models and modeling but does vary between these two dimensions.

H3: The three levels are specific due to the five aspects nature of models, multiple models, purpose of models, testing models and changing models. The level of understanding varies across all these aspects.

**METHODS**

Data Collection
On the basis of the model of model competence, forced choice-tasks were developed (Krell & Krüger, 2010). In each task, a concrete model is presented and the respondent has to rank the three levels of the relevant aspect according to his or her own understanding of the shown model. The ranking options were generated deductively and are therefore rather abstract and close to the theory (e.g.: the model looks like the original). This is why the forced choice-tasks are assessing what Treagust et al. (2004) call a “theoretical understanding” (p. 16) of models and modeling. In the present study, six tasks for each aspect of the model of model competence (30 tasks in total) were used to investigate the students’ understanding of models and modeling. A multi-matrix-booklet-design was conceptualized to keep the number of tasks for every single student small. The sample consists of 1,180 students at the age of 13-16, currently attending public schools (Gymnasium) in Berlin, Germany.

**Data Analysis**

The data was analyzed using the partial credit-model, a Rasch model which allows for partial scoring (cf. Yen & Fitzpatrick, 2006). In order to test whether the theoretically described levels are general (H1) or specific in terms of dimensions (H2) or aspects (H3), three different measurement models were specified and evaluated in the software ConQuest (Wu, Adams, & Wilson, 2007).

H1: The one-dimensional (1D) measurement model does not differentiate between the tasks of the five theoretical aspects and therefore postulates three general levels of understanding and handling models.

H2: The two-dimensional (2D) measurement model subsumes the tasks of the aspects nature of models and multiple models on the one hand and the aspects purpose of, testing and changing models on the other hand.

H3: The five-dimensional (5D) measurement model was analyzed which postulates the independence of the five aspects (but allows correlations between them).

The three measurement models are nested models (cf. Schermelleh-Engel, Moosbrugger, & Müller, 2003) which deduce directly from the structure of the model of model competence (“choose the model first”; Yen & Fitzpatrick, 2006, p. 124) and which are operationalizations of the three hypotheses H1, H2, H3 formulated above. In order to evaluate the goodness of the measurement models, two information indices were computed: the cAIC and the ssaBIC which are variant forms of the AIC and the BIC. Unlike the AIC, the cAIC takes the sample size into account and the ssaBIC does not overemphasize the parsimony of the measurement model as strong as the BIC (cf. Burnham & Anderson, 2004). The cAIC and the ssaBIC can be used to compare the goodness of different measurement models. When doing this, the smallest value of each index indicates the relatively best fitting model (cf. Kang, Cohen, & Sung, 2009). To test whether the differences between the fit of nested measurement models are significant, one can additionally perform a chi square difference test (cf. Schermelleh-Engel et al., 2003).

**FINDINGS**

Table 2 shows the information indices for the three measurement models. The results show that in both cases the 5D measurement model describes the data (relatively) best. The chi square difference test shows that the differences between the fit of the three measurement models are significant (Table 3). This is an additional argument for the 5D measurement model. If the differences had not been significant, one should have preferred the most parsimonious model which is the 1D model in the present case (cf. Collins & Lanza, 2010).
Table 2: The values of the cAIC and the ssaBIC for the three measurement models (1D, 2D, 5D).

<table>
<thead>
<tr>
<th></th>
<th>cAIC</th>
<th>ssaBIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D</td>
<td>13,355.56</td>
<td>13,426.29</td>
</tr>
<tr>
<td>2D</td>
<td>13,325.86</td>
<td>13,392.15</td>
</tr>
<tr>
<td>5D</td>
<td>13,288.41</td>
<td>13,327.70</td>
</tr>
</tbody>
</table>

Table 3: Results of the chi square difference test. The value of the chi square ($\chi^2$), the number of the degrees of freedom (df) and the significance (sig.) are shown.

<table>
<thead>
<tr>
<th></th>
<th>$\chi^2$</th>
<th>df</th>
<th>sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D - 1D</td>
<td>34.14</td>
<td>2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>5D - 2D</td>
<td>64.45</td>
<td>12</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>5D - 1D</td>
<td>98.59</td>
<td>14</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Using the 5D measurement model, fit statistics for the single tasks were computed. The wMNSQ for the overall item parameter is 0.95-1.07, whereas the wMNSQ for the step parameter is 0.88-1.08. Both values indicate a good fit between the tasks and the 5D partial credit measurement model (cf. Bond & Fox, 2001). The findings reported here are in line with the results of a preliminary study with a smaller sample of 901 students (Krell & Krüger, submitted).

**DISCUSSION**

The findings show that the 5D measurement model describes the data best. In other words, the students’ understanding of models and modeling varies between five distinct aspects. For example, the understanding of the aspect purpose of models may be less elaborated than of the aspect testing models (and vice versa). Justi and Gilbert (2003) reported similar results on the basis of their theoretical assumptions. The authors concluded that their interviewees “do not hold coherent ontological and epistemological views” (p. 1382). According to the model of model competence (Table 1), the theoretically described levels do not seem to be general, too. In this sense, the current outcomes are similar to the results reported by Crawford and Cullin (2005) because the authors assumed a structure with four general levels (limited, pre-scientific, emerging scientific and scientific) but were not able to describe general levels of understanding empirically. Whereas both Justi and Gilbert (2003) and Crawford and Cullin (2005) investigated the teachers’ understanding, in the present study students were tested. All in all, the more recent findings (Justi & Gilbert, 2003; Crawford & Cullin, 2005; the present study) suggest not to think about the understanding of models and modeling as a whole but to differentiate between distinct aspects.

Regarding the features of the forced choice-tasks, it can be said that they measure an abstract and therefore a more theoretical understanding of models and modeling. Tregust et al. (2004) assessed the students’ understanding of models in a similar way and also analyzed lessons in which the students had to handle models concretely. From their findings the authors conclude that a “theoretical understanding of the scientific model is not necessarily related to practical applications of the teaching model” (p. 16). Similarly, Terzer et al. (2011) show that the students’ understanding of models and modeling is not the same when being asked on an abstract level (forced choice-tasks) and on a concrete level (multiple choice-tasks developed by Terzer). When assessing the students’ concrete understanding of models and modeling, the level of understanding seems to be general (Terzer et al., 2011). The different findings of Grosslight et al. (1991) on the one hand and Justi and Gilbert (2003) as well as Crawford and Cullin (2004, 2005) on the other hand could depend on their slightly different theoretical assumptions (i.e. the different aspects/dimensions). But the forced choice-tasks and the multiple choice-tasks were both developed on the basis of the model of model competence.
This strongly supports the findings of Treagust et al. (2004) who report differences between the students’ theoretical and practical understanding of models.

**PROSPECT**

Talking in terms of school practice, the absence of general levels of understanding could indicate a lack in the students’ understanding of scientific models and the modeling process in science because an elaborated understanding of models and modeling means to understand all aspects in a sound manner (Justi & Gilbert, 2003). Therefore, teachers should reflect on all the five aspects explicitly (cf. Justi & Gilbert, 2003; Fleige, Seegers, Upmeier zu Belzen, & Krüger, in press).

The differences between the results of the abstract and the concrete operationalizations have to be investigated further (Terzer et al., 2011). So far, the data of both kinds of operationalization have been analyzed separately. Therefore, the next step will be a common analysis of the data to work out direct correlations between the students’ abstract and concrete understanding of models and modeling. Doing this, one should find out whether there is a more elaborated theoretical understanding as it is reported by Treagust et al. (2004). In addition, the model of model competence is evaluated using open ended (Grünkorn et al., in press) and hands on-tasks as well (Hänsch & Upmeier zu Belzen, 2011). Looking at the results of the forced choice-tasks in particular, further analysis will focus on the closer description of the students’ theoretical understanding of models and modeling. For this purpose, a latent class-analysis (Collins & Lanza, 2010) will be conducted in order to describe several distinct patterns of understanding.

**REFERENCES**


STUDENTS’ UNDERSTANDING OF THE NATURE OF SCIENCE: A LARGE SCALE TRANS-NATIONAL COMPARISON

Maria-Antonia Manassero-Mas², Ángel Vázquez-Alonso¹, Antoni Bennàssar-Roig³ and Antonio García-Carmona⁴

¹Department of Psychology. University of Balearic Islands, Spain, ma.manassero@uib.es
²Department of Applied Pedagogy and Educational Psychology. University of Balearic Islands, Spain, angel.vazquez@uib.es
³Department of Biology. University of Balearic Islands, Spain, abennassar@uib.es
⁴Department of Didactic of Science. University of Seville, Spain, garcia-carmona@us.es

Abstract: A large sample of young science students from several countries has been surveyed to assess their understanding of the nature of science. Each student anonymously answered 15 questions, which involve scoring one hundred sentences that are scaled into a set of attitudinal indices. The global results show an overall neutral (grand mean score around zero) students’ understanding, though the detailed examination of indices identifies many differences across countries and positive or negative profiles across issues. The diagnosis that emerges from the data is quite complex, as appropriate beliefs coexist with some inappropriate beliefs within any country. Further, each country’s profile allows delineating its specific achievement in relation to nature of science understanding. The results suggest the general need to improve the quality of science teaching on nature of science issues, and especially in those countries whose profile tend to be lower than others. The implications of the methodology and the results for the research, for teaching science, and for teacher training on the nature of science and technology issues are discussed.

Keywords: nature of science, science-technology-society, evaluation of conceptions, student conceptions, trans-national comparison.

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BACKGROUND, FRAMEWORK, AND PURPOSE

Science education scholars consider today the nature of science an essential educational goal, and a basic component of the scientific and technological literacy for all, and yet an innovative element of science education, which adds some difficulty to its teaching (Millar & Osborne, 1998).

PISA (OECD, 2010) defines scientific literacy as an individual’s scientific knowledge, and the use of that knowledge, to identify scientific issues, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues; their understanding of the characteristic features of science as a form of human knowledge and enquiry; their awareness of how science and technology shape our material, intellectual and cultural environments; and their willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

Summing up, PISA’s scientific literacy is made up of knowledge “of” science and knowledge “about” science; the former is the cognitive knowledge of the features, theories and laws that
rule the physical, earth and space, living, and technology systems; the latter involves the understanding of science and technology as a form of human knowledge and enquiry, their attitudinal awareness of how science and technology shape our material, intellectual and cultural environments, and their attitudinal willingness to engage, as a reflective citizen, with the ideas of science, and in science-related issues. It seems clear that PISA literacy component involves knowledge, process and attitudinal components about science and technology, designing on its own the nature of science (and technology) (hereinafter, NoS).

Since the early 70s, the empirical research shows repeatedly and consistently that the students do not have a proper understanding of NoS. The students often hold traditional, positivist (logical empiricist), and idealistic views of S&T, which are close to the list of myths on science (McComas, 1996), or contrary to the list of consensuses on NoS (Bartholomew, Osborne & Ratcliffe, 2004). They do not distinguish between science and technology and the current relationships among science, technology and society (STS), do not understand the role of the scientific method, theories and hypotheses, models, creativity and tentativeness in the validation of scientific knowledge (for instance, Lederman, 2007).

RATIONAL

The diagnostic studies of students’ NoS understanding have been scarcely conducted in Latin contexts and using big research samples. This paper examines the science students’ NoS beliefs from a large sample of young students, who are running their last year in high school (grade 12) or their first year in college, in the framework of an international cooperative investigation (Iberian-American Project of Evaluation of Attitudes Related to Science, Technology and Society, Spanish acronym PIEARCTS) across seven Iberian-American Spanish and Portuguese-speaking countries (Vázquez, Manassero, & Bennassar, 2009). The sample of PIEARCTS consists of several layers:

i) Young students, who begin their college or finish their high-school (17 to 19 years old),

ii) Veteran students in their last year of college, master or just graduate (22 years and older),

iii) In-service teachers of all educational levels.

The new PIEARCTS methodology allows the use of inferential statistics (ANOVCAs) to hypothesis testing, for instance, to compare countries or groups of students. The research tries to answer the following questions: Which are the global strengths and weaknesses of NoS understanding of the Iberian students’? Are there differences among countries in students’ NoS understanding?

METHODS

The main contribution of this paper is the presentation of a new instrument, scoring method, and quantitative methodology to assess NoS conceptions that allow implementing easy and reliable applications to large representative samples, using inferential statistics to check out differences between groups or setting up cut-off points for deepening the qualitative analyses of the quantitative data.

Sample

The participants are 4,533 young students engaged in the last high-school year or the first college year (most of them about 17 to 19 year-old) and have already made a choice for school science. The sample approximately splits in equal halves by sex (53% men) and by the two questionnaire forms (1 or 2) that answered each student (Form 1, 52%).

Instrument
The participants’ NoS conceptions are assessed through a paper and pencil multiple-choice items, which allow easy and reliable applications to large representative samples, due to a new methodology and model design. Each item poses an issue, using a common and simple non-technical language style; a variable number of sentences, each labelled with a letter A, B, C…, follow the stem text. Each sentence states a particular reason that explains a position (belief) on the stem issue. Each item is identified by a five-digit number: the first digit signifies the dimension, and the remaining digits represent themes and sub themes; the five digits plus a letter identifies the items’ sentence variables (Vázquez, Manassero & Acevedo, 2006).

The PIEARCTS research team consensually selected 30 items that are allocated into two 15-item paper and pencil research booklets (F1 and F2) from the Questionnaire of Opinions on Science, Technology and Society (Spanish acronym, COCTS). The COCTS is an adaptation into Spanish language and culture of the VOSTS and TBA-STS empirically developed items (Aikenhead & Ryan, 1992; Rubba, Schoneweg & Harkness, 1996), which form a pool of 100 multiple-choice items that inherits the credit of VOSTS and TBA-STS, as one of the best paper and pencil instruments to evaluate NoS&T beliefs (the empirical development of items warrants the item validity). The 30 items contain 200 sentences and cover the dimensions displayed in table 1.

Table 1. Dimensions of the general structure of the issues and labels of the 30 questions included in the two questionnaire forms (Form 1 and Form 2). Note the correspondence between each dimension and the first number of the question label; a short description of the question content (sub themes) follows each key number.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Form 1 Items (key / issue)</th>
<th>Form 2 Items (key / issue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Definition of S&amp;T</td>
<td>F1_10111 science</td>
<td>F2_10211 technology</td>
</tr>
<tr>
<td></td>
<td>F1_10411 interdependence</td>
<td>F2_10421 interdependence quality of life</td>
</tr>
<tr>
<td>b) STS Interactions</td>
<td>F1_30111 STS interaction</td>
<td></td>
</tr>
<tr>
<td>Influence of society in S&amp;T</td>
<td>F1_20141 country’s government policies</td>
<td>F2_20211 industry</td>
</tr>
<tr>
<td></td>
<td>F1_20411 ethics</td>
<td></td>
</tr>
<tr>
<td>Influence of S&amp;T in society</td>
<td>F1_40161 social responsibility</td>
<td>F2_20511 educational institutions</td>
</tr>
<tr>
<td></td>
<td>contamination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F1_40221 moral decisions</td>
<td>F2_40211 social decisions</td>
</tr>
<tr>
<td></td>
<td>F1_40531 life welfare</td>
<td>F2_40421 Application to daily life</td>
</tr>
<tr>
<td>Internal Sociology of science</td>
<td>F1_60111 motivations</td>
<td>F2_60521 gender equity</td>
</tr>
<tr>
<td></td>
<td>F1_60611 women under representation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F1_70231 consensus decisions</td>
<td>F2_70711 national influences</td>
</tr>
<tr>
<td></td>
<td>F1_80131 advantages for society</td>
<td></td>
</tr>
<tr>
<td>c) Epistemology</td>
<td>F1_90211 scientific models</td>
<td>F2_90111 observations</td>
</tr>
<tr>
<td></td>
<td>F1_90411 tentativeness</td>
<td>F2_90311 classification schemes</td>
</tr>
<tr>
<td></td>
<td>F1_90621 scientific method</td>
<td>F2_90521 role of assumptions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F2_91011 epistemological status</td>
</tr>
</tbody>
</table>

Procedures

The respondents rate their agreement (1, total disagreement; 9, total agreement) on each item sentence. These scores are scaled into quantitative indices (-1, +1), whose meaning is invariant across all sentences: the higher (lower) the index score, the higher (lower) the
respondent’s opinion fitness with the current knowledge from history, philosophy and sociology of S&T (Vázquez & Manassero, 1999; Vázquez et al. 2006). Averaging the sentence indices within each item, four new indices are produced: three indices for the three groups of sentences (categories) and one global index for the whole item. Thus, this scheme describes the student’s thinking on NoS through over one hundred and fifty invariant indices (sentence, category and item indices).

The indices allow the use of inferential statistics for hypothesis testing, which can be applied to compare countries or groups, or to set up cutting points for identifying the strengths (highest positive), weaknesses (lowest negative), and neutral beliefs (Vázquez, Manassero & Acevedo, 2006). The criteria to achieve relevance are the statistical significance ($p < .001$), and the effect size, or the differences expressed in standard deviation units ($d > .30$).

**RESULTS**

The results are expressed through the global item index (weighted average of the sentences through categories) for the 30 applied items in the two booklet forms; the results are analyzed according to the different places (two countries contribute with two places each) where the instruments were applied (each labelled by a letter and a number to preserve confidentiality).

**Figure 1.** Overall mean results for the 15 items of F1 booklet items across all the places.

**Figure 2.** Overall mean results for the 15 items of F2 booklet items across all the places.

Overall, the results show a broad similar evolution across items for the different places; thus, the highest positive (strengths) or lowest negative (weaknesses) scores for the issues are approximately the same for all places. They are selected by the relevant effect size criterion: mean indices higher or lower than one third of a mean standard deviation with respect to the overall mean of the place, though the differences between countries in some items is so high that the strengths and weaknesses are selected on the global average.
The sorted list of F1 and F2 items, which represent students’ strengths, is the following: F1_30111 STS Interaction, F1_40161 Social Responsibility contamination, F2_50111 Union two cultures (lower than those of F1), and F2_60521 Gender equity (lower than those of F1).

The list of items, which represent students’ weaknesses, is the following: F1_20411 Ethics, F1_40531 Life Welfare, F2_10211 Technology, and F2_40421 Application to daily life.

The second feature showed in the figures are some marked differences in NoS understanding between countries and sites, as some sites are getting better and worst achievements than others, and some items display big differences among sites. For instance, sites A1, R2 and E4 display overall top averages along the items, while sites S2 and P7 have got bottom averages.

Further, many items set up big differences among sites, as most of the items exhibit differences greater than .10 (d > .30) between their top and bottom sites, although these relevant differences display somewhat different homogeneity among sites. Just three items exhibit the lowest differences among the sites, which hardly get the relevance criterion (d > .30): F2_40131 social responsibility information, F2_50111 union two cultures, and F2_60521 gender equity.

Obviously, as PISA rules for science achievement, the noticeable differences in NoS understanding among sites suggest the potential relationships between NoS and the school science curriculum design and implementation, or concerns about the effective presence, treatment, and teaching implementation of NoS issues.

The methodology allows the application of inferential statistics in hypothesis testing, which is applied here to compare the NoS beliefs of young students of E4 site against veteran students and in-service teachers. The overall differences among the three groups are not statistically significant, although a noticeable trend is that young students display poorer NoS understanding (lower scores) than the other two groups (veteran and in-service teachers), which exhibit a quite remarkable equality between them (figures 1 and 2).

![Figure 1](image_url)

Figure 1. Comparison among young students, veteran students and in-service teachers of the E4 site for the 15 items of F1 booklet items.

When testing the differences among groups along the 30 issues of the two forms, the general trend exhibit some additional nuances, as a few items present significant differences of the young students in relation to the other groups, which means young students score significantly under the other two groups. In F1, the inferiority of the young students in relation to other groups is significant for the item issues F1_30111 STS interaction, F1_40161 social
responsibility on pollution, F1_40531 Welfare and standard of living. In F2, young students have scores significantly below the other groups on issues F2_10421 Interdependence, Quality of life, F2_20511 educational institutions, F2_50111 Union of two cultures and F2_90521 true assumptions.

In contrast, the testing of differences also uncovers two issues (F2_40421 Resolution in your daily life and F2_90111 Observations) that attract attention because they provide a counterpoint to the previous dominant trend: young students show higher scores than the other groups, and the differences are relevant for the group of young students.

![Figure 2. Comparison among young students, veteran students and in-service teachers of the E4 site for the 15 items of F2 booklet items.](image)

**CONCLUSIONS AND IMPLICATIONS**

The instrument and methodology presented here allows cheap, quick and easy assessments of the NoS, a quality that is specially appreciated for applications to large samples, as is the case presented in this paper. Moreover, the assessment instrument and method fit the requirements recently suggested by Allchin (2011) for appropriately assessing functional NoS understanding: authentic context, well-informed analysis, adaptability to diagnostic, formative or summative evaluation, adaptability to single, mass, local or large-scale comparative use and the respect for relevant stakeholders. Further, the research project PIEARCTS is an example of large-scale applications across seven countries and involving over 16,000 valid answers (Bennàssar-Roig, Vázquez-Alonso, Manassero-Mas, García-Carmona, 2010; Manassero et al., 2010).

On the basis of the quantitative use of indices, the study identifies some qualitative features, such as strengthens (conceptions that fit the experts’ current knowledge) and weaknesses (conceptions that oppose the experts’ current knowledge) on NoS understanding of young students.

The lack of deep differences between young students, veteran students, and in-service teachers, when higher scores would have been expected for science teachers, is a disappointing result, as it points the overall lack of attention to NoS issues in science education. First, the lack of big differences between young and veteran students points out to the relative inefficacy of higher education graduate science programs to adequately teaching NoS. Second, the absence of differences between science veteran students and in-service teachers points out to the inefficacy of teacher pre-service and in-service training to prepare teachers on NoS. Thus, science curriculum design and implementation, and science teacher
training have to be redesigned so that the teachers and students’ understanding of NoS could be improved.

Most of these strengths and weaknesses are widely shared across countries and the different groups surveyed through the questionnaires (Bennássar-Roig, et al., 2010). As PISA does for science achievement, this study also evidence differences in NoS understanding among countries, which refer back to the development of science education in each country (contents in school curricula, teacher training, practices of teaching, etc.). In fact, the results might be used to highlight national strengths and weaknesses, and develop programs to improve NoS teaching and NoS learning.

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THE NATURE OF SCIENCE IN PHYSICS COURSES: PLACE AND ROLE OF THE HISTORY OF SCIENCE

Laurence Maurines\textsuperscript{1} and Daniel Beaufils\textsuperscript{1}
\textsuperscript{1}DidaScO, University Paris-Sud 11, France

Abstract: Physics and chemistry programs at the secondary school level in France recommend introducing components of the history of science. Emphasis is placed on a “cultural” dimension, which is poorly defined but essentially refers to elements of epistemological nature. But there is no connection between this implicit epistemological aim of science education and the learning goals specified for each thematic domain: they only concern the scientific concepts and process. Our main issue is to examine the possibility to communicate a more authentic image of the nature of science with the introduction of the history of science. We begin by demonstrating how our historical and epistemological analysis of physics led us to distinguish different aspects of scientific activity that may constitute key points for a didactical transposition and can be chosen as different learning goals. We then show how these goals (e.g. “interactions between scientists” or “science-technology relationships”) can generate kits of texts and activities for students that are both appropriate to a given level of instruction and fulfil such a specific epistemological objective. Our innovative approach is based on the nature of investigative situations (with experiments or not): the reading assignment is divided among all students and the synthesis consists in collectively drawing a diagram providing a synoptic visualization of the epistemological objective. Finally we discuss the tensions that our choices created among teachers.

Keywords: nature of science, history of science, secondary level teaching, innovative pedagogical units, teachers

INTRODUCTION

The issue of the nature of science (NoS) is more suggested than explicitly stated in the French science programs at the secondary school level. It may be extrapolated from their introductive components that recommend introducing an historical perspective. Emphasis is placed on a “cultural” dimension, which is poorly defined but essentially refers to elements of epistemological nature. But there is no connection between this implicit epistemological issue of science education and the learning goals specified for each thematic domain: they only concern the scientific concepts and process. Moreover, the programs suggest very few examples of activities based on the history of science (HS): most of them are means to learn scientific content and convey a reductive and false image of science. This is the same case for the science textbooks (Beaufils & Maurines, 2008; Guedj, Laubé, & Savaton, 2007). Their historical elements refer to only one person who is most often well known. Discoveries seem to happen immediately and are linked to a specific date; they appear to be animated by a superhuman mind possessed with intuitive genius, arising from an unequivocal idea or a decisive experiment. Besides, many teachers share an outmoded vision of the sciences (empirically inductive and naively realistic) and unconsciously convey this stance to their students through the way they teach. Moreover, they are unaware of the epistemological issue of science learning (Robardet & Vérin, 1998; Pélissier, Venturini, & Calmettes, 2007).
This situation, close to the one described abroad by many science education researchers (Höttecke & Silva, 2011; Larochelle & Désautels, 1992; Lederman, 2007; Matthews, 2003; Mathy, 1997) working on NoS led us to begin a research program that examines whether the introduction of HS in teaching can help to address the epistemological issue of scientific education. Our position is unique in France. Almost all other recent work concerned with the use of HS in physics courses (Décamp & de Hosson, 2010; de Hosson & Kaminski, 2007; Guedj, 2005) does not explore this aspect but focuses on the acquisition of scientific concepts; the historical elements introduced in most of these different studies concern controversies over the interpretation of specific phenomena and are minimalized.

The underlying stake of our research is that historical resources and student-centered activities, which offer a heightened sense of the reality of NoS, can provide a broader scientific cultural integration for students and have a positive effect on their relationship with science as an academic discipline. This is a significant societal issue, given students’ current disaffection with the branches of basic science. We confer with Solbes and Traver (2003) on that point. Moreover, following Driver, Leach, Millar and Scott (1996), we also believe that the acquisition of a scientific and cultural background allow students to become responsible citizens, capable of understanding and taking action in a world where science and technology occupy a predominant place.

RESEARCH QUESTIONS AND METHODOLOGY

The issue of greater authenticity in representing NoS in physics classes has several main aspects. First, how do we characterize this authenticity and which approach do we choose in order to address the cultural and democratic rationales for including NoS in science teaching? Second, what pedagogical goals can be pursued and can historical examples be found that are compatible with science programs and students’ academic level? If so, what historical resources and activities support these objectives and how are they integrated in the traditional teaching focused on science content? Third, how teachers judge these innovative proposals and put them into practice? The area of specialization of our team members led us to explore these questions in the case of physics.

Our work initially consisted of complementary analyses concerning the nature of science and scientific activity, the high school programs, the science textbooks, the students’ and teachers’ epistemological conceptions and teachers’ practices. They led us to 1) discern different characteristics of scientific activity and knowledge that may constitute key points of an authentic image of science upon which didactic goals may be based a priori; 2) identify “historical situations” (e.g. the interpretation of the law of refraction) that could be integrated into physics’ curricula. We then created and designed didactic resources and activities for students that were both appropriate to a given level of instruction and fulfilled a specific epistemological objective. Before spreading our pedagogical propositions, we sought to improve them in taking into account teachers’ feedback. We contacted various colleagues who had replied to a first inquiry on their relationship to the use of the history of science in teaching (Beaufils, Maurines, & Chapuis, 2010) and expressed interest in receiving complete pedagogical resources. The information returned to us completed the first synthesis of material that resulted from a session of ongoing teacher training (January 2009). Some results of this stage of our research are given in the last section of this paper.
DESIGN OF INNOVATIVE PEDAGOGICAL UNITS

Epistemological learning goals

In our project, HS is not considered *per se* but as a means to introduce students to 20th century philosophical ideas on science. This is a richer understanding of how science works mainly today, and not in the past, that we expect. Consequently, we sought to identify through the analysis of the history of physics what aspects of physics can be considered as temporal invariables. Since the intersection of the various studies of science is where the most authentic view of science is revealed, we based our analysis on the philosophy, history, psychology and sociology of science. This approach led us to the “consensus view” of the nature of science which comprises a set of aspects widely accepted in standard documents (Project 2061 for example) and philosophy of science (Lederman, 2007).

In our opinion, introducing the history of science highlights episodes of scientific activity of various lengths seen through a series of critical filters relative to the NoS such as show that 1) scientific activity is a nexus of controversy; 2) scientific knowledge follows criteria of internal coherence, simplicity, and strength and has to be confronted with facts based on observation and experiments; 3) a scientist does not work in isolation but within a community that participates in testing established scientific knowledge; 4) there is a relationship between technical questions and the evolution of ideas; 5) etc. We would like to observe first of all that since these goals focus on epistemological aspects, they are independent of conceptual or procedural learning objectives, which therefore can be only secondary, if not completely absent. This position is close to the one presented by Lederman and Abd-El-Khalick (1998) about activities relating to the nature of science.

Historical resources for students and historical investigative situations

Several didactic choices determined the direction of our pedagogical research: elaborating resources and suggesting activities for students beyond simply providing documentary resources for teachers, offering collective activities to students that permit complementary or contradictory interactions, the development of common, shared knowledge, etc. In other words, the choice reflected our attempt to integrate the resource kits with investigative situations which pair texts with experiments or not. With a view to suggesting a wide variety of activities to teachers and pupils, we have developed resource kits based on short documents, designed according to the stated goal. The documents present information in different forms—texts, diagrams, drawings, etc.—which is usually taken from texts written by historians or scientists keen on history but also from primary sources or which we can have written. Our primary objective is to propose students with texts easily to read.

Historical experimental investigative situations

In some of our first proposals (Maurines and Mayrargue, 2005, 2007), the reading of historical texts is coupled with doing an experiment described or inspired by the texts, thereby following the hypothesis that some teachers prefer situations that link texts with experiments, since they might not want to deviate from their preferred conceptual or procedural learning goals. This approach becomes most meaningful when the targeted goal stresses the process of validating a model by confronting its prediction with facts derived from observation or/and experimentation (e.g. in insert 1). The choice seems artificial, however, and therefore
inappropriate in relation to a goal like studying “interactions between scientists.” In this type of situation, the risk of drifting off course toward an emphasis on knowledge and methods is especially high. It is fundamentally important to explicit the epistemological dimension during the last phase of the teaching situation. Höttecke et al (2010) whose approach is close to the one proposed here suggest to arrange furniture in the classroom in order to create an “epistemological corner”, i.e. a place dedicated to the reflection on the nature of science.

Insert 1: A possible structural outline of an activity combining texts and experiments (Topic: the dispersion of white light through a prism)

<table>
<thead>
<tr>
<th>Appropriating or/and constructing a problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>- create a conflict by reading texts: compare de Dominis’ and Newton’s models.</td>
</tr>
<tr>
<td>- state hypotheses inspired by the texts: Is white light homogeneous and are colors created uniquely by the action of the prism?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resolving of the problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>- develop experiments that allow the hypothesis to be tested, revealing its consequences.</td>
</tr>
<tr>
<td>- confront expectations with the results of the experiment</td>
</tr>
<tr>
<td>- invalidate the model of homogeneous white light</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Establishing knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>- scientists test their explanations against facts that result from observation and experiments; they valorize those explanations that allow for a large number of facts to be interpreted simply.</td>
</tr>
<tr>
<td>- white light is heterogeneous and composed of colored light</td>
</tr>
</tbody>
</table>

Historical documentary investigative situations and synthesis diagrams

More recent proposals (Maurines, Beaufils, & Chapuis, 2009) are based on the collective analysis of resource kits designed to examine a specific characteristic of scientific activity: the interactions between scientists, the relationships between technical questions and the evolution of ideas, for instance. Insert 2 presents a possible structural outline of such documentary investigative situation.

Insert 2: A possible structural outline of an investigative situation based on texts

<table>
<thead>
<tr>
<th>Appropriating or/and constructing a NoS problem:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- integrate the topic into the teacher’s learning sequence for the class; highlight questions of a historical nature: how do we know that...?</td>
</tr>
<tr>
<td>- specify a specific problematic that sets the goal to be achieved</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resolving the problem:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Documentary work (as homework or in class, individual or in small groups)</td>
</tr>
<tr>
<td>- present documentary resources.</td>
</tr>
<tr>
<td>- distribute the documents among the members of the class</td>
</tr>
<tr>
<td>- read documents and prepare the lesson in which the synthesis will be done, guided by instructions that specify the type of information to be culled from the text; who, what, how, why, etc. (in relation to the documents and the question).</td>
</tr>
<tr>
<td>2) Reaching a synthesis (students will do this collectively based on each class member’s contribution)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Establishing knowledge:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- the teacher generalizes the results that were found by students and shows the connection between how science worked in the past and the present situation.</td>
</tr>
</tbody>
</table>

The kits are usually composed of about ten interrelated documents, characterized by a “point of entry” directly related to the goal to be achieved: this might take the form of scientists’ names, for instance, or technical achievements. Contrary to the stories proposed by Clough (2010), each document gives only some information. The reading assignment of the kit is divided among all members of the class and the collective synthesis is made under the
teacher’s “guidance”. Thus, enough information can be provided to students in order to convey a more realistic image of NoS without discouraging poor readers and requiring too much time. The synthesis that is made in class is supposed to produce a specific type of result: a diagram that provides a synoptic visualization of the information that has been gathered and illustrates the targeted goal. Insert 3 presents an example of such diagram that students could produce. As far as we know, this collective strategy and type of synthesis activity have never been proposed by science educators contrary to the previous one which pairs texts with experiments (Höttecke, Henke, & Riess, 2010).

**Insert 3: Example of diagram on the epistemological objective “interactions between scientists” and the topic “laws of refraction”**

![Diagram](image)

**BY WAY OF CONCLUSION: SOME REMARKS ON THE FIRST FEED-BACKS OBTAINED FROM TEACHERS**

The majority of responses given by the sixteenth teachers who answered the questionnaire on the feasibility of our proposal on the topic of refraction and on the epistemological goal “interaction between scientists” indicated that the objective was interesting, stressing the fact that the evolution of science, with its complexity and social dimension, should be demonstrated. Responses were largely positive in favor of presenting this kit at the grade 10 level but some colleagues’ expressed reserve and were concerned that the intellectual level of the students would be overly challenged by documentary activities involving reading that was beyond their critical ability. The answers to the questions on the pedagogical organization range from positive feed-back arguing for a simple activity that could be integrated into the complete set of activities students are asked to perform, to negative feed-back, arguing that the texts were too difficult, that the synthesis students were asked to make (a diagram) was too abstract, and that the context was too exclusively cultural, independent of notional learning, requiring highly motivated students. They also argue that they are not trained on the NoS. All this send back to a curriculum issue (conception of science programs and aims which are assigned to them) but also to an issue centred on the teachers (their training and their conception of science teaching, and more fundamentally, of science).
NOTES

1 Other proposals can be found in Maurines (2010).
2 Our approach is similar to Aduriz-Bravo’s one (2010).
3 Since the modern period.
4 We agree with Mc Comas, Clough and Almazroa (1998) on that point.
5 The arrows are different because they are different types of interactions. Continuous double arrow: direct interaction. Dashed double arrow: epistolary interaction. Dotted single arrow: knowledge of the works. Red double arrow: interaction with controversy. Red single arrow: opposition of points of view.

REFERENCES


THEORETICAL MODELS FOR (MESO)CHEMISTRY: PARADIGMATIC FACTS

Cristian Merino\(^1\) and Mercè Izquierdo\(^2\)
\(^1\)Instituto de Química. Pontificia Universidad Católica de Valparaíso, Chile
\(^2\)Departamento de Didáctica de las Ciencias Experimentales, Universidad Autónoma de Barcelona, España.

**Abstract:** We wonder about the meaning that Chemistry can have for those who are learning it without identifying themselves with the academic pursposes of the discipline, because they are unable to, due either to their age or context (school). From this reflection, we propose a modelling orientation for chemistry teaching. We use the “theoretical model” notion from the current cognitive approaches of the philosophy of science, which propose a semantic concept of scientific theory which facilitates the approach between phenomena and the theories that explain them. We developed a chemistry at a “meso” level, which gives a very important function to the atomic theory, but not protagonism, which belongs to “Chemical Change.” The study of the exemplary changes following the rules and the languages of chemistry guides and gives coherence to the lessons, where “Ideal Chemical Facts” are built. The cognitive dimension leads us to identify the coherence between the students’ experimental interventions, their abstract representations, and the languages they use to explain what they are doing, what is happening, and why it is happening. We identify the modelling process with the progressive fit between these three dimensions of human cognition. The discourse analysis of university students from a “chemistry for all” course allow us to identify the relationships the students established between their representations, experimental interventions and the languages they used.

**Keywords:** Chemistry, Representation, Language

**BACKGROUND, RATIONALE AND PURPOSES**

Research on chemistry teaching based on models has become increasingly important, due to new educational aims that require the students to be competent in the use of the scientific knowledge to their own reality. This new curricular orientation, in elementary as well as in university education, pushes us to urgently design a new way for teaching chemistry. This research includes diverse fields: the study of experiences or phenomenology (Andersson, 1990); classroom discourse analysis (Mortimer, 1998); pedagogical content knowledge (Shulman, 1986); the “perspectival realism” (Giere, 1988). All of them asked themselves how the “school chemistry activity” (SCA) which makes the students put their cognitive capacities (think, do, and communicate in a coherent way) on trial is built (and developed). In order to do this, it is necessary that the experimental situations they are intervening can be mentally and symbolically represented (Gilbert, de Jong, Justi, & Van Driel, 2002), to create a standpoint for chemical-problem solution, to generate chemical approach to the phenomena. In our modelling process analysis we also apply our theoretical framework (Author & Adúriz-Bravo, 2003) and an epistemological approach as has been explained by Sénsey (2008) et al (2009). In this paper we wonder how tuned languages, representations and experiments (LER) in a modelling process to acquire (get into) a relevant school chemical knowledge.
Framework

We present the students some carefully-chosen chemical phenomena as “problems” that provide the context and opportunity to introduce the essential and elementary and chemical ideas, which give sense to the problem; it can be solved and related to other problems important to chemistry. We “modelled this phenomenon”: we “colonized” it by applying to it the chemical ideas (laws of chemical change) and by representing it, as far as possible, through atomic theory which will allow to introduce the formula language, basic to communicate “what is happening” when a chemical change takes place. Because of this, a “natural change” becomes a chemical change, that will be a MODEL to identify some others that are similar. The data presented for this communication are taken from the student’s discourse regarding a phenomenon: “pyrolysis (carbonization) of wood”. This phenomenon, as well as all the rest that will become “Chemical Change Models” has to follow the “rules of the chemistry play”:

a) Some substances disappear and others appear.

b) The elements are preserved. The mass is conserved (in atoms, including electrons)

c) The substances react in fixed proportions (chemical equations)

d) Energy is conserved (chemical bond)

e) In the final state, there is no more “chemical potential” available.

METHODS.

We had a video recording of three sessions where the students used models to explain the pyrolysis of wood and answer the teacher’s questions. The students worked in three-to-four people groups. The models had been built freely with different materials (play dough, strips of paper, 3D models to represent molecules...). The recordings were transcribed and analyzed identifying “interactivity segments” and “acting patterns”: Inquiry (I), Start (S), Feed-Back (F), Evaluation (E). The dialog was coded in terms of the foreseen transitions; (L↔R; R↔E; E↔L…) and some “transition maps” were made, and then interpreted. The data were gathered from the instrument showed below (tabla 1) and were represented with diagrams (fig. 1)

<table>
<thead>
<tr>
<th>Paradigm/ Sentences</th>
<th>Complement that enriches the explanation of the sentence</th>
<th>Transition L-E-R</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students’ phrases</td>
<td>Elements that provide the context</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Transition language-experiment-representation

Simbology

- More than 2 frequencies
- More than 1 frequency
- One frequency

1 It is frequent that the models represent scientific entities as the phenomenon interpreted, and not the phenomenon itself, where the entities stem from.
RESULTS

Different diagrams that could be compared with each other (see table 2) as well as with the diagrams from the same student’s discoursese in different pedagogical situations were obtained. Although only in few situations all the transitions are present, we have been able to prove that in the cases where the modelling process could be applied, this was successfully accomplished (see table 2).

![Table 2: Diagrams for six students in the same class session.]

CONCLUSIONS AND IMPLICATIONS

We think that choosing the pyrolysis of wood as “paradigmatic fact” was the right decision to make, because it is an everyday phenomenon that can be intervened, that starts and ends, and which also allow to mass. It requires a control (for the wood not to burn) that is available for the students and that allows them to intervene in the process in an autonomous way, and when doing so, they can recognize the combustion process. We think it interesting to have identified in the student’s discoursese the transitions between their references to the real phenomenon to the representation in the model and to their “giving a name” which gets more scientific as they manage to interpret the change with the entities represented by the model.

We have been able to empower the meaning of the terms: model, paradigmatic fact and representation in our research project about the “chemical chemistry” teaching. He have realized that the relationships between thinking, experimenting, and communicating based on a determined planning that gathers the phenomena in groups or “fields with the same conceptual structure”, allow to rebuild “facts of the world” according to the chemical theory, that will become “Theoretical Models” of the chemical theory. What we call “School chemical-change model” gives us the conductive thread to develop the curriculum focusing on the paradigmatic examples from Chemical Change.

Acknowledgements

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STUDENTS’ ANALOGICAL REASONING WHEN PARTICIPATING IN MODELLING-BASED TEACHING ACTIVITIES

Nilmara B. Mozzer\(^1\), Rosâria Justi\(^1\), & Paula P. Costa\(^1\)

\(^1\)Education Post-graduation Programme, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

Abstract: One of the ways students can express their mental models is by drawing analogies between an already known domain and the domain of the scientific topic they are learning about. The literature stated that analogical reasoning is comprised of some sub-processes but in previous studies we have shown that in regular teaching situations, students do not spontaneously experience all of them, thus resulting in problems in students’ learning. In this paper, we have identified evidence of such sub-processes in students’ analogical reasoning when they participated in a modelling-based teaching about solubility that occurred in a regular classroom. From them, we discuss the influence of modelling-based teaching conducted in regular classrooms on students’ experience all the sub-processes of analogical reasoning.

Keywords: modelling-based teaching, analogical reasoning.

INTRODUCTION

Analogy are relational comparisons between a familiar and an unknown domain (Duit, 1991; Gentner, 1983; Glynn, 1991). Therefore, from drawing an analogy, one expresses a partial representation of an idea. This implies that analogies are models (Duit, 1991).

Although many researchers recognise its importance, there is no general agreement in cognitive science literature (for instance, Gentner, 1989; Holyoak & Thagard, 1997; Vosniadou & Ortony, 1989) about how the analogical reasoning process occurs. In attempting to understand analogical reasoning, this process has been decomposed into basic sub-processes: (i) access: one or more relevant known domains should be accessed; (ii) mapping: one familiar domain is mapped on to the target domain by identifying systematic correspondences between them; (iii) elaboration of inferences about the target, favouring domain understanding; (iv) evaluation of the match, followed by changes in the inferences in order to fit them with special aspects of the target; and, sometimes (v) generalisation: extension of inferences to all cases in which they could be applied.

The drawing of analogies is a daily action of human reasoning. However, the situation is different in the context of science classrooms where, in general, teachers present analogies to students and ask them only to understand the mapping relationship. In the science education area, few studies have been conducted on analogical reasoning in which students draw, use, and modify their own analogies (Cosgrove & Schaverien, 1996; Kaufman, Patel, & Magder, 1996; Pittman, 1999; Wong, 1993). In our previous study (Mozzer & Justi, 2010), we analysed how students reason analogically when they are asked to draw analogies for a scientific target domain they are currently learning about. We showed that, in general, students have no difficulties in performing both the access and the mapping sub-processes. On the other hand, they do not perform the other sub-processes (evaluation of the match, proposition of inferences, and generalization) unless they have been specifically asked to do so. As a consequence, students may either develop alternative conceptions from improper matches between non comparable relations and/or attributes of both domains, or misuse the analogy in other contexts. This implies that if students’ drawing of their our analogies is to be
part of teaching activities, teachers must foster them to accomplish all the analogical reasoning sub-processes. This would favour their involvement in those sub-processes that are not spontaneous for them.

As analogies are models, one of the possible ways to involve students in all analogical sub-processes would be by engaging students in modelling-based teaching activities. According to Justi and Gilbert (2002), modelling is a dynamic and non-linear process comprised of four main complex stages: the production of a mental model; the expression of that model in any mode of representation; the tests of the model; and the assessment of the resulted model, that is, the consideration of the scope and limitations of the model.

RESEARCH QUESTION
When students participate in modelling-based activities produced and conducted from the Justi and Guilbert’s perspective, they experience all these stages. As the skills involved in such experiences are, in some way, similar to those involved in analogical reasoning, we have supposed that modelling-based teaching could contribute to students’ accomplishment in performing all the analogical reasoning sub-processes. Assuming this hypothesis, in this paper we discuss the following question: How can modelling-based teaching conducted in regular classrooms contribute to students’ experience all the sub-processes of analogical reasoning?

METHODOLOGICAL ISSUES
Context and sample
A series of modelling-based activities was developed to support the teaching of solubility to 15-16 year-old students (Activities 1-4 in figure 1). Such activities aimed at favouring students’ creation of a qualitative model that explained sub-microscopic aspects involved in dissolving. Such a teaching sequence is similar to other teaching sequences we had developed in the sense that the activities were elaborated in such a way as to favour students involvement in all stages of the modelling process. On the other hand, this teaching sequence has a unique characteristic: students are required to express their models both in a concrete mode and by drawing analogies. This is justified by our intent to investigate students’ generation of analogies in a modelling context.

These teaching activities were applied in a regular class comprised of 36 students (15-16 years old) in the last month of the academic year. They had already studied properties of substances and chemical bonding around 8 months before, but from a traditional approach. As far as our data showed, initially they had several improper conceptions about both topics and none of them showed an acceptable understanding about how a substance dissolves into another. Moreover, they had previous experience with neither modelling-based activities, drawing of analogies in science classes, nor investigative experimental activities. On account of this, before the modelling-based activities, students participated in an extra activity based on the Teaching-with-Analogy (TWA) model (Glynn, 1991) involving the analogy between the solar system and the Bohr atomic model (Activity 0 in Figure 1). It aimed at facilitating students’ understanding about the meaning of analogies in science.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Identification of the relevant characteristics of both the Bohr atomic model and the solar system. Mapping the similarities between both domains, with special emphasis on the relational mappings. Identification of the differences between both domains.</td>
</tr>
<tr>
<td>1</td>
<td>Presentation of two systems (water + piece of chalk and water + powder grape</td>
</tr>
</tbody>
</table>
Elaboration of prediction about what is going to happen in each system when their components were mixed.
Conduction of the empirical experiments and registration of the observations.
Discussion about possible differences between previous predictions and actual observations.

2 Elaboration of a model to explain the observed phenomena at the sub-microscopic level and expression of such model in a concrete mode of representation.
Drawing of analogies to explain the represented phenomena.
Identification of the similarities and differences between the aspects compared.

3 Observation of new behaviour of one of the systems (mix of powder grape juice in water without stirring the system).
Attempt to use the previous analogies in order to explain the new behaviour of this system.
If necessary, modification or rejection, followed by new elaboration, of previous analogies and/or concrete models.

4 Extension of possible analogical inferences to other situations related to the modelled phenomenon.

Figure 1. Brief description of the teaching activities.

Throughout all lessons, students have worked in groups comprised of 5-6 students. The teacher guided the whole process. As the chemistry teacher had no previous experience with modelling-based teaching, before the starting of the study, the first author met her twice. In such meetings, they discussed about the teaching context, the students’ previous ideas related to the topic, the modelling-based teaching, students’ drawing of analogies, the relationships between analogies and models, and the conduction of the modelling activities. So, these meetings were essential in order to improve the teacher’s understanding on both the modelling-based teaching process and the purpose of our study. The teacher has participated in both the meetings and the lessons with great enthusiasm.

During the lessons, she has tried to favour students’ discussions by stimulating them to critically analyse, to modify, and, sometimes, to reject their analogies and other models. She has also asked them: to explain their choices about modes of representation, as well as the meaning of particular codes of representation; and to explain their ideas, to think about the coherence of the ideas expressed in their concrete models and analogies. Finally, she also tried to produce generative questions – those that “cannot be answered on the basis of stored information but require the genuine solution of a new problems” (Vosniadou, 2002, p. 358) in order to favour students’ rethinking about specific aspects of their models.

Data gathering and analysis

All five lessons were video-recorded by using two cameras. The videos focused on the discussion between the students in their original groups and those between the students and the teacher. Additionally, the discussions in each of the groups were audio recorded, the written material produced by the students was collected, and the concrete models they produced were photographed.

From the integration of such data, we produced case studies for each of the students’ groups. The most complete of such case studies (that is, the one that include most of the moments in which students were producing and discussing their concrete models and analogies) was from a group comprised of six students. Such a case study was analysed aimed at making it evident the elements of the modelling activities that had contributed to students’
experiencing of all the analogical reasoning sub-processes, and to the development of their knowledge about the dissolving process.

**CONCLUSIONS AND IMPLICATIONS**

From the analysis of our results (not presented here due to the limitation of space), we identify the elements of the modelling-based teaching that may have contributed to students experiencing all the sub-processes of the analogical reasoning. They are presented in figure 2. From them, we draw our conclusions and present some implications of this study.

<table>
<thead>
<tr>
<th>Sub-process of analogical reasoning</th>
<th>Action in the modelling-based teaching</th>
<th>Modelling stage</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access and mapping</td>
<td>&quot; After the observation of each phenomenon, request to produce a mental model, and to express it as concrete models and as analogies that could explain them. &quot;&lt;br&gt;&quot; When necessary, request explanations about the mapping between the compared domains. &quot;</td>
<td>Production of mental model.</td>
<td>1 2 3</td>
</tr>
<tr>
<td>Evaluation of the match</td>
<td>&quot; Opportunity for students to observe new empirical evidence. &quot;&lt;br&gt;&quot; Explicit request (from both the activities and the teacher) to express the similarities and differences between the compared domains. &quot;&lt;br&gt;&quot; Explicit request, from the teacher, to analyse their comparisons for the new knowledge built during the class discussions. &quot;</td>
<td>Tests of the model.</td>
<td>3</td>
</tr>
<tr>
<td>Proposition of inferences</td>
<td>&quot; Request to produce explanations based on students’ previous explanations (and identified by the teacher as close to the scientific accepted ones). &quot;&lt;br&gt;&quot; Teacher’s elaboration of generative questions. &quot;&lt;br&gt;&quot; Request to compare systems that behave differently from each other when students were already able to explain the behaviour of one of them. &quot;</td>
<td>Production of mental model.</td>
<td>2 3 4</td>
</tr>
<tr>
<td>Generalisation</td>
<td>&quot; Presentation of a new context in which students could try to extend their possible inferences from the process they had experienced, thus providing evidence of the knowledge they had built during the modelling activities. &quot;</td>
<td>Assessment of the resulted model.</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 2. Summary of the relationships between the analogical reasoning sub-processes experienced by students in different modelling stages and activities.

Our results showed that specific requests from of the modelling activities (mainly those related to the production, expression, and tests of students’ models), as well as some teacher’s actions when conducting the process (mainly the promotion of discussions between students, the elaboration of generative questions, the request for explanations concerning the codes of representations used in different models, and the request for justification of all their
expressed ideas) have clearly favoured the occurrence of all the analogical reasoning sub-processes (including those that are not common in students’ analogical reasoning).

Besides these relationships, we can also discuss other contributions from the drawing of analogies in the modelling-based teaching context. One of them concerns the visualization of sub-microscopic entities (and relationships between them) from the observation of macroscopic phenomena (Justi & Gilbert, 2006). As those students had already studied the chemistry topic, we suppose their previous learning about it was insufficient for supporting students’ production of initial representations (concrete models and analogies) at the sub-microscopic level that included information concerning the interaction between particles and the intensity of such interactions. In the teaching situation analysed in this study, when the teacher provide them opportunities to express their own comparisons, she could realise that, although they were asked to make representations at the sub-microscopic level, they established mere appearances matches (those characterised by the mapping of macroscopic properties between the compared domains). This has supported the teacher’s decision of discussing the meaning of such levels, and making clearer to students what they should represent and explain in their models. Moreover, the simultaneous expression of students ideas through concrete models and analogies, and the teacher’s request for explanations concerning the codes of representation used in each model have also favoured the teacher’s access to some students’ ideas, as well as her following actions aiming at favouring students’ reasoning at the sub-microscopic level.

Our results also support our view that the use of modelling-based activities like those used in this study can facilitate the evolution from the establishment of mere appearance matches to the drawing of analogies. This is so because relational comparisons are made when a more advanced knowledge about a given domain is being developed, or has just been developed (Vosniadou, 1989), that is, when students are already able to integrate the macro and the sub-micro levels in building a more comprehensive understanding (Justi & Gilbert, 2006).

In this study, we had evidence that the modelling-based activities provided opportunities for that students experienced all the analogical reasoning sub-processes in a way similar to the one scientists experience when building scientific knowledge. Following the process of evolution of students’ ideas in the direction of those accepted in science, we had evidence that the drawing, expression, and changing of students’ analogies contributed to their learning about the chemical topic. On the other hand, other studies would be necessary in order to investigate if the drawing, expression, and changing of students’ analogies can also support students’ learning about the process of building scientific knowledge – which is also one of the aims of modelling-based activities produced from the Justi and Gibert’s modelling diagram perspective.

Finally, as our study has shown, the involvement of students in all the analogical reasoning sub-process cannot be viewed as an autonomous process, that is, the teacher should guide the students in performing specific sub-processes. Therefore, it is essential to include discussions about modelling-based teaching, analogical reasoning, and teachers’ actions that may foster the integration of such processes in teachers’ educational contexts. This may result in the development of specific elements of their pedagogical content knowledge, which may support them in facing the challenges of conducting more authentic and effective science education.
ACKNOWLEDGMENTS

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PROSPECTIVE SCIENCE TEACHERS’ APPRECIATION OF SCIENCE: THE CASE OF THEORY OF EVOLUTION VS. INTELLIGENT DESIGN

Ebru Z. Mugaloglu¹ and Sibel Erduran²
¹Bogazici University
²University of Bristol

Abstract: The study aimed to explore the prospective science teachers’ appreciation of science in the case of evolution vs. intelligent design (ID). It introduced a proxy indicator of “appreciating science” in the case of evolution theory. “Appreciation of science” was defined as recognising the value or excellence of science and therefore choosing the scientific explanation between the clashing worldviews in question. Data were collected from 31 prospective science teachers’ written arguments in the context of evolution versus intelligent design (ID). Four distinct groups of claims were identified following qualitative analyses of the written arguments: (a) “Accept Evolution and Teach Evolution only”, (b) “Accept Evolution & ID and Teach Both”, (c) “Accept Evolution, Teach Evolution and Talk about ID” and (d) “Do not Accept Evolution and Teach ID only”. We concluded that %39 of the participants did not appreciate the theory of evolution in explaining the origin of species. We also concluded that accepting a scientific theory was a necessary but not a sufficient condition for appreciating science because 32% of the prospective science teachers accepted evolution and ID as science and equated ID with evolution theory. Furthermore prospective science teachers who appreciated science and who did not appreciate science on the basis of our definition of appreciation, refer to the same aspects of nature of science (NOS) such as tentativeness and testability to justify their positions about teaching evolution and/or ID. This outcome implies that either these prospective science teachers do not have a clear understanding contemporary NOS views or these aspects of NOS are not sufficient in enhancing prospective science teachers’ understanding of evolution. In the context of the broader goals of scientific literacy, one of the implications of the study is to develop and integrate activities in teacher training programs in order to enable prospective science teachers to understand the nature of scientific theories and to distinguish a theory from a pseudo scientific explanation. We suggest that improved understanding of NOS will facilitate better appreciation of science.

Keywords: appreciation of science, evolution, intelligent design

INTRODUCTION

In a scientifically literate society, people are expected to distinguish between what is science and what is not, and construe a scientific theory as the best explanation for a particular natural phenomenon at a particular time period. For instance, evolution theory is a scientific theory explaining the origin of species whereas intelligent design (ID) is a pseudo-scientific explanation about the origin of life. The ability to distinguish a scientific explanation from a pseudo-scientific explanation is an important aspect of scientific literacy. However, according to a survey in 2006, in countries such as Turkey and US, public acceptance of evolution theory is very low (Miller, Scott, & Okamoto, 2006). Peker, Comert & Kence (2010)
indicated that the acceptance of evolution as a scientific theory in Turkey was low not only in public but also among undergraduate students in science education, biology education and biology. Peker et al’s study (2010) illustrated that only 27.75% of undergraduate students with a science background, who were supposed to teach evolution in Turkey, accepted evolution as a scientific theory. It is also worthwhile to note that there are wider institutional and cultural concerns that impact how evolutionary theory is perceived and communicated in Turkey. For example, in 2009, a special issue of the official magazine of the Turkish Scientific and Technical Research Council (TUBITAK) about Charles Darwin and the theory of evolution were censored just before it went to press (Nature, 2009). In addition to this censorship, ID is being disseminated in Turkey quite systematically and the social pressure increases on teachers to teach it as science. “Turkey is now a major source of the creationist propaganda outside the USA, and is especially significant in relation to its influence on Muslim populations in Europe” (Cornish-Bowden & Cardenas, 2007, p.113). These efforts are sometimes supported politically in the European Union (EU) and elsewhere. For example, in a response to an EU Resolution, European Centre for Law and Justice (2007) described ID as a scientific theory and equated it to the theory of evolution.

FRAMEWORK AND PURPOSE

Wider theoretical context for the study of scientific vs. pseudo-scientific explanations is epistemology. Within traditional epistemology, it is widely accepted that belief, truth and justification are the necessary conditions of knowledge. This is known as the justified true belief (JTB for short) theory (Musgrave, 1993). So, if knowledge is considered as one of the primary outcomes of science education, then it follows that science teachers are also responsible for facilitating their students’ acquisition of scientific beliefs. However, teaching science does not guarantee a change in students’ potential inconsistent beliefs especially about science topics such as evolution or astronomy. Smith and Siegel (2004) argue that science education must aim for understanding rather than knowing so that beliefs of students do not become an issue in science classes. In other words, unlike knowing, believing is not a necessary condition for understanding. Instead of believing, Smith and Siegel (2004) emphasize appreciation of justifications as one criterion of understanding. Moreover, in order to develop public understanding of science, it is “necessary for students to develop an appreciation of both the power and limitations of scientific knowledge claims” (Driver, Leach, Millar and Scott, 1996).

In the Oxford English Dictionary (2010), to ‘appreciate’ is defined as “to recognize as valuable or excellent”. The present study introduces a proxy indicator of “appreciation of science” in the case of evolution theory. The topic of evolution is quite significant in science education as evidenced, for instance, by the dedication of a special issue of Science & Education Journal in 2010, and therefore perfectly fits the purpose of introducing a proxy indicator of appreciating science. Broadly speaking “appreciation of science” is defined as recognising the value or excellence of science. Moreover, Deboer (2000) suggests enhancing public understanding and appreciation of science for the larger goal of scientific literacy. For the purpose of this study we expect appreciation of science to be inclusive of favouring scientific explanations, for example, choosing the scientific explanation when presented with clashing worldviews about a critical issue. In order to promote appreciation of science in science classrooms, then, teachers would be expected to place a higher status to the theory of evolution as a scientific theory than to intelligent design. Within this framework, the present study aimed to explore the prospective science teachers’ appreciation of science in the context of evolution vs. intelligent design (ID). In order to approach the research problem,
prospective teachers’ written arguments were investigated to outline how they chose to justify their preferences to teach evolution and/or ID in a science class. We define argument as justified claims about a position taken, in this context, claims about evolution vs. ID—a definition which is consistent with others in the literature (Erduran, 2007). Moreover, we analysed how prospective science teachers referred to widely taught aspects of Nature of Science (NOS) in order to justify their positions. Thus, it was aimed to analyse the role of their NOS views in their preferences about teaching evolution and/or ID. According to mainstream NOS views, scientific knowledge is: (a) Tentative, (b) Subjective Based on empirical evidence, (c) Theory-laden, (d) the product of human imagination and creativity, (e) inferential, (f) influenced by society and culture as well as by scientists’ values and experiences (Abd-el-Khalick, 2001; Schwartz & Lederman, 2002).

METHOD

The study was guided by the following research questions: (a) What is the nature of prospective science teachers’ appreciation of evolutionary theory in Turkey? (b) What is the role of teachers’ views on the nature of science (NOS) in relation to their position regarding the theory of evolution?

Data were collected from prospective science teachers in a state university in Turkey. The university accepts students from all over Turkey who are successful in the nationwide University Entrance Examination. This examination is centrally organized by the Student Selection and Placement Centre every year, and all high school graduates who want to be science teachers must sit for it. Successful students may attend a four-year program in a Faculty of Education. Upon graduation, the prospective teachers in this study would be qualified to teach science in primary schools (grades 6–8). The sample comprised 31 third- and fourth-year students: 11 male and 20 female.

The participants watched the NOVA documentary film titled “Judgement day: Intelligent Design on Trial” (2007). The film problematises the teaching of evolutionary theory versus intelligent design, and is based on a true story of conflict in a community and a school district in the United States. After watching the NOVA documentary film, prospective teachers were asked to write a position paper to clarify and justify their individual positions on teaching evolution and designed in a science class. The written arguments of the prospective teachers were analysed to identify their appreciation of science. Moreover, two prospective science teachers (one who appreciated evolution and one who did not appreciate evolution) were chosen for case study analysis. In both cases, statements of prospective science teachers were scrutinised so as to reveal how their NOS views influenced their positions. More specifically, we traced how prospective science teachers referred to characteristics of science and scientific knowledge such as tentativeness, subjectivity, falsifiability, theory-ladenness, explanation of nature, natural or supernatural causality, method and inquiry processes including questioning, hypothesis, observation and data collection.

RESULTS

As a result of qualitative analysis of written responses (Table 1), four distinct groups of arguments were identified:

Group (a)-Accept Evolution and Teach Evolution only: The first group included 15 prospective science teachers. They clearly accepted evolution as a scientific theory. As for their positions on their future science classes, all prospective science teachers in this group argued in favour of only teaching evolution in science classes. Analysis of their arguments showed that they gave a higher status to the theory of evolution as a scientific theory than to ID.
Group (b)-Accept Evolution & ID and Teach Both: The second group included 10 prospective science teachers. They considered ID as a scientific theory and equated it with the theory of evolution. As for teaching evolution and/or ID in their classes they opted for teaching both.

Group (c)-Accept Evolution, Teach Evolution and Talk about ID: This group included 4 prospective science teachers. Similar to the prospective teachers in Group (a) they accepted evolution as a scientific theory and argued in favour of teaching evolution in science classes. However, differently from Group (a), they also argued that ID should be mentioned in science classes as a pseudo scientific explanation. Yet, they gave a higher status to the theory of evolution as a scientific theory than to ID.

Group (d)-Do not Accept Evolution and Teach ID only: The fourth group included 2 prospective teachers. They clearly rejected the theory of evolution based on their religious beliefs. They argued that evolution theory imposed atheism and in this sense it was also religious. They also argued that science was not able to answer the origins of life as the question was not scientific. They argued that the best role for science in this issue was to work on how the Designer created the universe. Based on these justifications they opted for not only teaching ID in science classes but also teaching against Darwinism and evolution.

Table 1. The results of the appreciation of science analysis

<table>
<thead>
<tr>
<th></th>
<th>Appreciate evolution</th>
<th>Do not appreciate evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accept evolution &amp; Teach evolution</td>
<td>Accept evolution &amp; Teach evolution and mention ID</td>
</tr>
<tr>
<td>Total (n)</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Total (%)</td>
<td>48.4%</td>
<td>12.9%</td>
</tr>
<tr>
<td>Total (%)</td>
<td>61.3%</td>
<td></td>
</tr>
</tbody>
</table>

Case Study Analysis

Two cases of prospective science teachers were selected for a detailed analysis of the role of nature of science (NOS) views in justifying their positions in teaching evolution and/or intelligent design in a science classroom.

The first case is from group (a), therefore, classified as “appreciates evolution”. The prospective science teacher argued that evolution was a scientific theory whereas ID was not science. Therefore, he preferred teaching evolution theory. While justifying this position, he referred to certain aspects of NOS. These included definition of ‘theory’, tentative, testable, and falsifiable nature of science. Regarding NOS he stated:
Yes, theory is not a fact but it is the best explanation we have about the rules of nature. ...all scientific explanations are tentative and testable ...scientific knowledge should be testable, falsifiable and tentative.

While arguing against ID he stated:

The followers of intelligent designers do not have much scientific data or explanations... ID is not a scientific explanation or a theory because all scientific explanations are tentative and testable...The proofs of ID were not scientific because scientific knowledge should be testable, falsifiable and tentative.

The second case is from group (b), therefore classified as “does not appreciate evolution”. This prospective science teacher argued that both evolution and ID are scientific in nature. Therefore, he opted for teaching ID as an alternative theory to evolution. Regarding NOS, ID and evolution he respectively stated the followings:

Scientists are not totally objective. They defend their own theories. But science is objective. In order to be objective students should learn different points of view.

ID proponents say that “nature of an intelligent cause or agent may not be directly observable, its effects on nature can be detected. When we think about these, it can be considered as science. If[ID] is just a theory and it is one of the explanations of origins of species. You are free to believe whatever you want...Evolution theory can be considered as science because some concepts of the theory are observable by the methods of science.

Some scientists accept this theory [evolution] as valid because of existence of many evidences that support the theory. Despite there are evidences about the theory, every new findings has potential to refute this theory [tentativeness]

So, according to this case, in order to be objective, students should learn both points of view. In this sense, they possess an equivalent position in the science classroom. While justifying this position, he referred to certain aspects of NOS such as objectivity, observable, evidence, and tentativeness, some of which were the same aspects as in Case 1.

CONCLUSIONS AND IMPLICATIONS

If prospective science teachers appreciate science and a group of prospective science teachers is examined in terms of their positions about teaching evolution and ID as science, then it is expected that they would favour evolution compared to ID in a science class. However in the present study, 38.7% prospective science teachers preferred teaching both or only intelligent design as a scientific theory. Therefore, the group of prospective science teachers did not appreciate science in the sense that we are considering “appreciation of science”. Hence, based on the results of the study, we conclude that the prospective teachers in the groups (a) and (c) appreciate science (as specified in our conceptualisation “appreciation of science”) whereas the participants in the group (b) and (d) do not appreciate science. Considering that all participants are prospective science teachers, the ratio who do not appreciate evolution theory can be considered to be quite high and thus of concern.

We also concluded that accepting a scientific theory was a necessary but not a sufficient condition for appreciating science. In other words, % 32 of the prospective science teachers accepted evolution in group (b). However, group (b) also accepted ID as science and equated ID with evolution theory. So, acceptance of evolution by itself might be a misleading criterion for science educators. Instead, appreciation might be a better criterion for evaluating the case
of evolution/ID. Moreover, from the case analysis, it was seen that prospective science teachers who appreciate science and who do not appreciate science refer to the same aspects NOS such as tentativeness and testability to justify their positions about teaching evolution and/or ID. This implies that either these prospective science teachers do not have a clear understanding contemporary NOS views or these aspects of NOS are not sufficient to enhance prospective science teachers’ appreciation of evolution. Therefore there is a need for further studies about the role of prospective science teachers’ NOS views in their appreciation of science.

As for the goal of scientific literacy, the implications of the present study are at least two-fold. First, activities, which enable prospective science teachers (a) to understand broader aspects of a scientific theory and (b) to distinguish a theory from a pseudo scientific explanation should be developed and included in teacher training programs. Second, as accepting a scientific theory is not a sufficient condition for scientific literacy, teacher training programs should emphasize appreciation of science to ensure that future teachers recognise the value and excellence of science.

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OPENING UP VALUES THROUGH HISTORY AND PHILOSOPHY OF SCIENCE

John Oversby

1Institute of Education, Reading University, Reading, RG6 1HY, UK Email: j.p.oversby@reading.ac.uk

Abstract: The 30 month, 8 country, EU History and Philosophy in Science Teaching (HIPST) project was established in February 2008. The UK part of the project has focused on three themes: a) the role of measuring in characterising the concept of temperature in history; b) induction as a historical method for establishing concepts of acidity; c) the historical use of the paper tools of chemical formulae and chemical equations to promote thinking about chemical processes. The first two themes are suitable, and are being trialled in lower secondary schools, with 5 comprehensive classes of Year 7 (11/12 year old pupils), in the South of England. The third theme is suitable for upper secondary pupils.

The materials produced for the first theme have been trialled and reviewed. The results so far have established the strength of a collaborative two cycle approach, involving a researcher from Higher Education, and practicing teachers in schools, producing relevant and robust resources for subject knowledge and the Nature of Science. Co-teaching has proved to be a successful tool for improving and increasing teacher subject knowledge about science and the history of science. Equally valuable, co-teaching has been a successful method for introducing pedagogical innovation, in comparison with a wiki, which has been less well used.

Pedagogical innovations that have engaged most pupils have included producing play scripts of scientific stories, and newspapers written in simple language. Using pupil work as a source of material for newspapers has also been an important innovation. the pupil newspapers have also served as a source of information for the teachers. Some new activities have been developed: lack of equipment in schools and skills of technicians was a barrier, and has led to specific training for the latter.

INTRODUCTION

The science education community's values are embedded, often implicitly, in its intended curricula. For example, the Science National Curriculum in England for 11 – 14 year olds (QCDA, 2009) states that: 'Pupils learn how knowledge and understanding in science are rooted in evidence. They discover how scientific ideas contribute to technological change – affecting industry, business and medicine and improving quality of life. They trace the development of science worldwide and recognise its cultural significance.'

Under Cultural Understanding, the same National Curriculum requires pupils to ‘recognise that modern science has its roots in many different societies and cultures,
and draws on a variety of valid approaches to scientific practice’.

The American Association for Advancement of Science (Project 2061) (AAAS, 1993, 2009) has ‘The images that many people have of science and how it works are often distorted. The myths and stereotypes that young people have about science are not dispelled when science teaching focuses narrowly on the laws, concepts, and theories of science. Hence, the study of science as a way of knowing needs to be made explicit in the curriculum,’ with development of some of the history to exemplify what should be done. Within the domain of History of Science, we seem to have variable and often rather weak guidance on its inclusion in Science Curricula. Williams (2002) surveyed the history of science in textbooks in England in 1999, following the integration of science into the mainstream school science curriculum. He notes that, in the related history curriculum, pupils have to have: chronological understanding; knowledge and understanding of events, people and changes in the past; historical interpretation; historical enquiry; and organization and communication. He used this framework to assess the place of history of science in readily available textbooks. His conclusions included (page 90):

- 14 – 16 physics has a larger volume of unexplained names in the history of science than biology and chemistry;
- the history of science is often included as a non-essential ‘add-on’ and serves little purpose in developing ideas and/or concepts;
- few accounts of the lives of scientists are given or how they worked;

Höttecke (2009) in his ESERA paper acknowledged the importance of History and Philosophy of Science towards school teaching, and the dearth of research about and curriculum resources for HPS teaching in schools. Höttecke gave the following research analysis of the impact of teaching HPS in Physics.

**RESEARCH QUESTIONS**

1. What are the purposes of including History and Philosophy of Science (HPS) in school curricula? What HPS is embedded in curricula?
2. What is presently known about the effect of HPS teaching in schools?
3. How do teachers respond to an explicit HPS teaching programme?
4. How do young learners respond to an explicit HPS teaching programme?

**METHODOLOGY**

1. The author undertook a desk study of National Curricula for Science, and of textbook resources. This was supplemented by a national meeting of researchers, teacher trainers, a philosopher of science, textbook writers, members of learned scientific societies, and a museum presenter.
2. The author undertook a desk study of literature relating to the effect of HPS teaching in schools
3. Three teachers undertook to teach a module on temperature to explore the effect of measuring on validating, and developing the reliability and accuracy of scientific equipment. The teachers took part in discussions by email, face to face conversations
that were recorded by hand, and one by constructing a reflection log
4. Teachers in two schools volunteered to trial materials with a total of 150 pupils aged 11-12 years old. Data collection included open-ended written questions, recording of learning in notebooks, field observations by the author, debriefing discussions by the author that include reports agreed with the teachers, pupil play scripts about a historical event, and a pre- and post-test about pupil views on HPS.

**DETAILS OF THE PROGRAMME**

The project that includes this work is part of the EU funded (FP7) History and Philosophy in Science Teaching (HIPST) project (HIPST, 2008-2010). The project is led from Germany and has activities in 8 European countries devoted to producing trialled resources for teaching HPS in schools, museums and universities. The project also aims to develop teachers' personal subject matter knowledge, pedagogical skills, especially in using innovative methods, and to introduce explicit historical and philosophical thinking into science teaching. In the case of philosophical considerations, this is directly linked to the Nature of Science, and in particular in the UK to the How Science Works part of the prescribed curriculum.

The UK part of the programme has three active themes:

a) historical characterisation of concepts through measuring, in the context of temperature;
b) historical conceptual identification and change, in the context of acidity;
c) historical development and use of paper tools, in the context of chemical formulae and chemical equations.
Themes a and b are being conducted with pupils in lower secondary schools, Theme c will be conducted in both lower and upper secondary schools. This paper focuses mainly on theme a, and is partly work in progress.

The topic of measuring is part of basic scientific training in UK lower secondary schools. Pupils have studied particle ideas as concepts, and it is important that the curriculum topic meshes with the stated curriculum.

**Philosophical issues**

a) What are the purposes of measuring in the scientific community?
b) What is meant by validity, reliability and accuracy in scientific measurement?
c) 

**Historical issues**

a) Is the human body a valid, reliable and accurate thermometer?
b) What is meant by standardisation, and how was it carried out for liquid-in-glass thermometers?
c) How was the constant-volume gas thermometer developed and used?

**Teacher materials**

A web site (www.ukhipsterinstruments, wikispaces.com) has been constructed for teachers engaged in the project. The web site has these major components:
a) a teachers' subject knowledge section incorporating scholarly material on subject matter knowledge about temperature, research on typical misconceptions, pedagogical content knowledge, and philosophical information,
b) a context section incorporating historical chronological information about scientific discoveries, significant cultural events and significant political events,
c) a scheme of work to show lesson progression with conceptual, misconceptions, historical elaboration, and philosophical elaboration,
d) a teachers' section that elaborates each lesson in turn.

In addition, the project has produced simple newspapers. There are staff newspapers to share news about the project as it progresses in schools. There are pupil newspapers, with relevant historical information about how temperature was measured in history, puzzles for pupils, reports of pupil surveys with friends and parents about what temperature is and how scientists measure, and a selection of play scripts about Gmelin's expedition across Siberia at the behest of Catherine the Great. The play plots Gmelin's report of the lowest temperature of -84.4C and the subsequent comment 50 years later by Thomson that the mercury would have frozen before then. The play scripts are used as a measure of pupil understanding of a problem in measuring temperature.

EVIDENCE

This report is based on the work of three teachers in two UK comprehensive schools, working with a total of five classes of 11-12 year old pupils, grade 7. Approximately 140 pupils have been involved so far. The study is still in progress. Up to date data and interpretation will be available for the conference.

1.
The Science National Curriculum in England for 11 – 14 year olds (QCDA, 2009) states that:
'Pupils learn how knowledge and understanding in science are rooted in evidence. They discover how scientific ideas contribute to technological change – affecting industry, business and medicine and improving quality of life. They trace the development of science worldwide and recognise its cultural significance.' It also states that pupils should be ‘using scientific ideas and models to explain phenomena and developing them creatively to generate and test, and be critically analysing and evaluating evidence from observations and experiments’.

Under Cultural Understanding, the same National Curriculum in England requires pupils to ‘recognise that modern science has its roots in many different societies and cultures, and draws on a variety of valid approaches to scientific practice’.

Internationally, there are variations in the emphasis paid to these issues. In recent Australian proposals, science is simply described as a ‘human endeavour’ with little reference to any historical outsourcing of this process. The New Jersey elaboration of the US Framework for Science states one aim of science is ‘to show students that scientific ideas and theories have a history of their own by tracing the evolution of our most important present-day paradigms’ (New Jersey, no date) The American Association for Advancement of Science (Project 2061) (AAAS, 1993, 2009) has ‘The images that many people have of science and how it works are often distorted. The myths and stereotypes that young people have about science are not dispelled when science teaching focuses narrowly on the laws, concepts, and theories of science. Hence, the
study of science as a way of knowing needs to be made explicit in the curriculum, with development of some of the history to exemplify what should be done. Urevbu and Omi (2005) describe in detail one approach to using the history of science in Nigeria in their paper delivered to the IHPST 2005 Leeds conference but do not provide evidence of success. Williams (2002) examined UK science textbooks for history of science content. The minimal content was an add-on, with little of the context in which the scientists worked, or about them as human beings. The history content is hardly used to develop conceptual understanding. Regrettably, there also significant numbers of errors in many textbooks.

2. Relatively little research is known about the effect of teaching HPS in schools and that which has been so far explored has mainly been in the physics domain (e.g. Höttecke, 2009 and Galili, 2009). Many researchers assert potential benefits, such as exploring difficult concepts through historical data, but there is only very modest evidence of success in this area in the literature (but see Wandersee, 1986, for one such example).

3. The teachers taking part in the trials programme are volunteers, so generalisation to other cases can not easily be made. However, these are the most positive conditions, so lack of success in these cases would be a serious setback. The main teacher in one school is a senior science teacher, and in the second school the main teacher is strongly supported by the leader of the science department. The teachers readily accept their initial lack of knowledge about the history of science, hence the production of pupil newspapers for the teachers' knowledge as much as for the pupils. They also accept their initial lack of knowledge about the philosophy of measuring, which has been developed through discussion with the author. A paper on measurement has been incorporated into the temperature wiki. The teachers claim, with strong justification, that lack of time in the face of persistent and demanding requirements for bureaucratic reporting make it difficult for them to devote significant time to studying for the project. Co-teaching, by the researcher and the teacher of each class, has been the major input source for their learning of historical and philosophical knowledge and of innovative pedagogical methods. Other sources of information, such as the web site, have played a very minor role so far, from debriefing interviews with the teachers.

4. There has been a wide variation in the way that pupils have engaged with the course. The increased emphasis on an adequate literacy base for pupils involved in the project has meant some difficulties, especially for some boys who seem to be the ones with the most serious problems in this regard. This has led, in some classes, to distracting behaviour by these pupils. The project has adopted a pragmatic approach to partially addressing the literacy issue by simplifying the language used, for example in the project pupil newspapers. However, the project participants have agreed that there is a limit to the extent that this can be done without compromising the accuracy of the ideas involved. This has meant that a small proportion (perhaps three or four in each class) have been somewhat disenfranchised from accessing some resources, such as the newspapers. Nevertheless, the great majority of the pupils show a positive attitude, in asking questions, in engaging with the practical work, in carrying out extra work at home, and in putting in extra personal time to completing play scripts. That these are often girls is only to be expected from the results of the
ROSE survey (ROSE, nd), that indicates girls dominating interest in humanistic science, and in more creative methods of recording their findings. Pupil recording of their findings in the form of annotated drawings suggest that the majority are understanding the science, the history and the philosophy in the lessons. The issue of literacy is a factor with a few pupils in the project recording their data, so that this evidence can not be collected from all.

CONCLUSIONS

The project has been successful in these respects:

1. Appropriate resources have been produced for teachers and pupils.
2. A rich dedicated web site has been provided, providing suitable guidance for both teachers and pupils.
3. The project is rather unusual (Innovative) in that the teachers are highly influential in the progress of the trials and resource production. This collaborative action between a colleague in Higher Education and teachers in schools is rather unusual.
4. The resources provided are innovative in a number of ways:
   a) the use of web sites with optional information and opportunity for blogs, discussion and teachers to create their own pages and upload their own files is innovative;
   b) the use of newspapers for revealing history of science, in pupil-level language, is unusual;
   c) the use of newspapers in which teachers and pupils can make their own contributions, is innovative;
   d) recreating historical experiments is unusual
   e) the use of play scripts for recording and assessing learning is unusual
   f) the use of newspapers for dissemination of progress to project members, including teachers, is unusual.

IMPLICATIONS FOR TEACHING

The project represents work in progress. Nevertheless, there are some clear implication from the project to date:
1. More resources for teaching HPS are needed and have been provided by the project.
2. Co-teaching is a powerful method for developing teachers' subject matter knowledge and innovative pedagogical skills.
3. Curriculum materials that mesh with the curriculum are more likely to be readily accepted.
4. Teachers need more time if curriculum change is to be securely embedded.
5. Individual pupil difficulties with literacy is a major barrier to engagement with science.
6. Some innovative pedagogies such as producing play scripts, and newspapers, can support increased engagement by pupils.
7. The project has unearthed some insecure learning in particle ideas that limit application e.g. use of the gas thermometer. The project has demonstrated a requirement for some changes to teaching the existing curriculum.
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ROSE web site at http://www.ils.uio.no/english/rose/


IBERIAN-AMERICAN STUDENTS’ AND TEACHERS’ PERCEPTIONS ABOUT GENDER EFFECTS IN SCIENCE

Silvia Porro¹; Claudia Arango¹; Diana Hugo² and Angel Vázquez Alonso³.
¹ Grupo de Investigación en Didáctica de las Ciencias (GIECIEN), Universidad Nacional de Quilmes, Argentina, sporro@unq.edu.ar
² Facultad de Ciencias de la Educación, Universidad Nacional del Comahue, Argentina, hugodi@infovia.com.ar
³ Department of Pedagogy Applied and Educational Psychology. University of Balearic Islands, Spain, angel.vazquez@uib.es

Abstract: In the Latin-American Project of Evaluation of Attitudes Related to Science, Technology and Society (acronym in Spanish: PIEARCTS), teachers and students from different countries were asked about their opinions on gender differences regarding Science. More than thirteen thousand students and teachers participated in the project. In this work, we analyze the results obtained by means of the Questionnaire of Opinions on Science, Technology and Society regarding the Internal Sociology of Science, focusing on two items, which inquire about the characteristics of scientists: Gender Equity (GE) and Women’s underrepresentation (WU) in Science. The results show that, in the overall sample from the different countries, the question on GE appears among those which present more positive attitudes in almost all the countries. On the other hand, as regards WU, Spain and Colombia present the most positive attitudes, whereas Brazil is among those with the most negative views. Nevertheless, the sentences corresponding to these topics appear both among the more positive and among the most negative. Women seem to be more conscious than men of the fact that the relationship between women and Science continues to be problematic. In the majority of the variables where they have found significant differences between women and men, it is the women who show a more suitable attitude.

Keywords: gender equity, nature of Science, Science – technology – society, evaluation of conceptions, teachers’ thinking.

BACKGROUND, FRAMEWORK, AND PURPOSE
The traditional view of Science is shown as neutral, rational and objective, and, even if this conception has been modified thanks to the critical trends of Philosophy of Science, which considers Science a human activity (Toulmin, 1972; Fourrez, 1992; Feyerabend, 1978) and, therefore, intrinsically subjective and dependent on the values of the people who construct it and on the theories on which it is based. The image or model of Science expressed by the majority of the people does not concur to these critical trends. One of the conceptions that stand out is a stereotyped model which conceives Science as the search for the objective truth about the physical world with an androcentral, positive and mystified view of this discipline that portrays man as the conqueror and controller of nature (Solsona, 2002, p.49). Teachers’ view of Science is very important since it is transmitted to students and; thus, it is disseminated and perpetuated. This transmission of the views towards Science regarding gender is often produced without the teachers’ conscious awareness, since it is also supported of by the use of sexist language on textbooks and other curricular material.

During the last few years, studies about the situation of female scientists in Spain done by the Spanish Foundation for Science and Technology (Spanish acronym: FECYT) (2005), as well as in Latin America (Pérez Sedeño & Gómez, 2008), indicate that women are under
represented in great part of the scientific disciplines. Opinions about this situation show that these realities are usually considered natural and inevitable. To modify this situation in the Scientific sphere, a change in the sphere of Education must be produced. One of the most important demands that are done to the educational system is related to the real capacity which the system has of being a tool that guarantees equality of opportunities (Freire, 1996). According to Subirats (2006, p. 229) “the path that is taking us from a situation of marginality and subordination to a situation of autonomy and intervention in mass decision-making processes is started through the educational system …”

RATIONALE
In this work we will present and analyze teachers’ and students’ opinions about gender equity and women under-representation in Science. These opinions were drawn from the corpus of the Latin American Project of Attitude Assessment about Science and Technology (Spanish acronym: PIEARCTS). The teachers who participated in this project work at the primary, secondary or higher educational level and come from all kinds of backgrounds. The students participants from different countries and are either finishing high school or attending university. Our objective is to show a diagnosis that allows us to answer, among others, the question posed by Ana Sánchez Bello (2002): What is the educational system’s failure since situations of social inequality regarding gender still continue to happen?

METHODS
Sample and instrument
This paper draws data from the international cooperative research project PIEARCTS, which intends to identify the nature of Science and Technology (NoS&T) beliefs across seven Iberian-American Spanish and Portuguese-speaking countries. NoS&T conceptions are assessed through the Questionnaire of Opinions on Science, Technology and Society (Spanish acronym: COCTS) (Manassero, Vázquez y Acevedo, 2003). This research tool allows easy and reliable applications to large representative samples. The PIEARCTS research team consensually selected 30 items that accomplish a balanced coverage of Science, Technology and Society issues. These items were distributed into two 15-item paper and pencil research booklets (F1 and F2). The participants in the study were 13,146 students and teachers (practitioner and pre-service) that anonymously completed a booklet, whose responses are scaled into a set of attitudinal indexes. Each participant responded one of the two questionnaires; approximately half of the participants answered Form 1 (7094), and the rest completed Form 2 (6052). In this work the results obtained in two items regarding the Internal Sociology of Science are analyzed, the first item refers to Gender equity (GE) and the second to Women’s under-representation (WU) in Science. As regards GE, participants are asked to reflect their opinion on the following:

- Working in Science or technology, women would make a good scientific work in much the same way that a good scientific man:
  There are no differences between men scientists and women scientists in terms of the way they do Science:
  A. because all good scientists do the work in the same way
  B. because men scientists and women scientists have the same pre-service
  C. because, above all, men and women are equally intelligent
  D. because men and women are equal in terms of what it takes to be a good scientist
  E. because we are all equal, regardless of the work we do
  F. because any difference in the way that scientists work in Science are due to individual differences. Such differences have nothing to do with being male or female
G. Women in Science would work somewhat differently, because by nature or education women have different values, opinions, perspectives or characteristics (such as patience).

H. Men would work in Science a little differently, because men perform this type of work better than women.

I. Women in Science would probably work better than men, because women must work harder in order to compete in a male-dominated field, such as Science.

In terms of women’s under-representation (WU) in Science, the participants were presented with the following scenario:

- Today in our country, there are much more men than women scientists. The MAIN reason for this is:

A. men seem to have more scientific capacity than women, women may excel in other fields

B. men are more interested in Science than women

C. the traditional stereotype that exists in society is that men are smarter and more dominant while women are weaker and less logical. This belief has resulted in more men becoming scientists, although women are as capable as men in Science.

D. schools have not done enough to encourage women to choose Science courses. Women are as capable as men in Science.

E. until recently it was thought that Science was a vocation in men and it was expected that most women work at home or in jobs traditionally performed by women, so the public image of Science has discouraged women -while encouraging men- to become scientists. But this is changing today: Science is becoming a vocation in women and more and more females are expected to work in Science.

F. women have been discouraged or not allowed to enter the scientific field. Women are just as interested in Science and just as capable of doing so as men are. However, established scientists (who are men) tend to discourage or intimidate potential women scientists.

G. There is NO reason to have more men scientists than women scientists. Both are equally capable of being good at Science and the opportunities today are similar.

**Procedures**

The respondents rate their agreement on a scale from 1 to 9, in which 1 is used to show total disagreement and 9 to show total agreement, on each sentence item. These items are scaled into quantitative homogeneous attitudinal-belief indexes (-1, +1), whose meaning represent the grade of correctness, according to the current knowledge from History, Philosophy and Sociology of S&T (Vázquez & Manassero, 1999; Vázquez, Manassero & Acevedo, 2006). Besides, the participant’s understanding of NoS&T is further represented by three indexes for the three categories in each item and the whole item index. This plan describes the participant’s thinking by means of over one hundred and fifty invariant indexes (sentence, category and item indexes).

The index scores allow the use of inferential statistics for hypothesis testing, which can be applied to compare groups (last-year high school vs. last year-university students, pre-service vs. in-service teachers), or to set up cutting points for identifying the strengths (highest positive), weaknesses (lowest negative), and neutral beliefs (Vázquez, Manassero & Acevedo, 2006). The criteria to achieve relevance are the statistical significance (p < .001), and the effect size of the differences (differences measured in standard deviation units; d > .30).

**RESULTS**

In the overall sample of different countries, there are more positive GE attitudes in almost
every country (except Mexico) and more positive WU attitudes in Spain and Colombia. On the other hand, these attitudes are more negative in Brazil. Nevertheless, sentences regarding these items appear both among the most positive and the most negative attitudes.

The attitudinal indexes of sentences that have the highest scores and positive above the cut point (half of standard deviation) are:
- To GE item, sentences D and F (Argentina, Colombia, Mexico, Spain and Portugal), and H (Argentina, Colombia, Spain and Portugal).
- To WU item, sentences A (all the countries), B (Argentina, Brasil, Colombia and Spain), C (Brasil, Spain, Mexico and Portugal), E (Brasil), F (Brasil and Colombia) and G (Brasil).

The attitudinal indexes of sentences that have the lowest scores and negative below the cut point (half of standard deviation) are:
- To GE item, sentences A (Argentina, Colombia, Spain and Portugal), C, B and E (Argentina, Colombia and Spain) and I (Colombia).
- To WU item, sentences H (Argentina, Spain, Portugal and Brasil).

**Differences between groups of teachers**

In Table 1 we show the results obtained for each of the countries, in terms of the index average for the whole item and to the standard deviation units of both items, for the groups of Exact and Natural Sciences (Science) and Human and Social Sciences (Non-Science), with the statistical significance corresponding to the differences between both groups.

**Table 1. Results of Science and Non-Science Groups of all the countries**

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<tr>
<td>Gender Equity Item</td>
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<tr>
<td>Argentina</td>
<td>0.203</td>
<td>0.227</td>
<td>0.190</td>
<td>0.235</td>
<td>0.620</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.090</td>
<td>0.305</td>
<td>0.132</td>
<td>0.317</td>
<td>0.198</td>
</tr>
<tr>
<td>Colombia (B.)¹</td>
<td>0.103</td>
<td>0.277</td>
<td>0.145</td>
<td>0.293</td>
<td>0.177</td>
</tr>
<tr>
<td>Colombia (I.)²</td>
<td>0.076</td>
<td>0.285</td>
<td>0.095</td>
<td>0.270</td>
<td>0.453</td>
</tr>
<tr>
<td>Spain</td>
<td>0.234</td>
<td>0.219</td>
<td>0.179</td>
<td>0.249</td>
<td>0.0001</td>
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<tr>
<td>Mexico</td>
<td>0.140</td>
<td>0.276</td>
<td>0.096</td>
<td>0.230</td>
<td>0.131</td>
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<tr>
<td>Portugal</td>
<td>0.118</td>
<td>0.284</td>
<td>0.269</td>
<td>0.284</td>
<td>0.068</td>
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<th>Women under-representation Item</th>
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<td>Argentina</td>
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<td>0.339</td>
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<td>0.180</td>
<td>0.257</td>
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<tr>
<td>Colombia (B.)¹</td>
<td>0.165</td>
<td>0.213</td>
<td>0.174</td>
<td>0.226</td>
<td>0.715</td>
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<tr>
<td>Colombia (I.)²</td>
<td>0.179</td>
<td>0.217</td>
<td>0.150</td>
<td>0.232</td>
<td>0.162</td>
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<td>Spain</td>
<td>0.181</td>
<td>0.305</td>
<td>0.161</td>
<td>0.318</td>
<td>0.289</td>
</tr>
<tr>
<td>Mexico</td>
<td>-0.023</td>
<td>0.304</td>
<td>0.028</td>
<td>0.293</td>
<td>0.433</td>
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<tr>
<td>Portugal</td>
<td>-0.069</td>
<td>0.303</td>
<td>0.132</td>
<td>0.261</td>
<td>0.001</td>
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</table>

¹Bogotá, ²Ibagué

In the GE item, there was a statistically significant main effect (less than 0.001), between the
group of Science and Humanities and Non-Science only for Spain, where the group of Science showed the most adequate attitude. In fact, this group has shown the most adequate attitude of all countries. As regards the WU item, there were significant differences between the complete samples of Science and Non-Science in Portugal, where the group of Non-Science showed the most adequate attitude between the two of them. Concerning this item, the group of Science from Spain has shown a more adequate attitude.

**Differences within the sample of Science**

**Among students**

Taking as the unit of analysis the results on the issues, there is a significant difference only in the items of GE for students from Spain, where older students show a more appropriate attitude than young students. Table 2 shows GE and WU items where significant differences were found between the senior students (S2) and young students (S1), and where the attitude of the S2 group from the stated country was more appropriate.

<table>
<thead>
<tr>
<th>Item/Sentence</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<tr>
<td>GE</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Spain</td>
<td>Argentina</td>
<td>Spain</td>
</tr>
<tr>
<td>WU</td>
<td>Brasil and Spain</td>
<td>Brasil, Colombia and Spain</td>
<td>Spain</td>
<td>Portugal</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

If we consider the GE item, no sentences were found where the attitudes of the S1 group from any country were more appropriate. With regard to the WU item, only in sentence “I” have we found a more appropriate attitude in a S1 group, the group from Brazil. These results suggest that the only country where university studies prompt the construction of a more appropriate attitude by students towards the GE item is Spain (Argentina one sentence).

On the WU item, it is worrying that in Argentina and Mexico no significant differences among young and senior students were found. Moreover, we have only found improvements in a few sentences in other countries (again it seems that it is in Spain where university studies have the most positive impact).

**Among teachers**

Regarding the GE item, there is only a significant difference between in-service teachers (T2) and pre-service teachers (T1). In Brazil, the most adequate attitude is shown by the T1 group. Concerning the issue of WU, there is a significant difference in Argentina, it was the T1 group the one that showed a most adequate attitude.

With respect to the sentences in Table 3, there are GE and WU items where significant differences were found between in-service teachers (T2) and pre-service teachers (T1) and where the attitude of the T2 group from some countries has been shown more suitable.

<table>
<thead>
<tr>
<th>Item/Sentence</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td></td>
<td>Brasil</td>
<td></td>
<td>Brasil</td>
<td></td>
</tr>
<tr>
<td>WU</td>
<td>Argentina and Brasil</td>
<td>Arg. and Brasil</td>
<td>Arg. and Brasil</td>
<td>Brasil</td>
<td></td>
</tr>
</tbody>
</table>

Significant differences were found regarding the GE item, with most adequate attitudes by the T1 group in sentence C in Spain, and G and H sentences, in Brazil.

According to these results, the only country where there are differences with opposite variations in some sentences of GE items is Brazil, where the T1 group has a more adequate attitude on the item as a whole, but the T2 group has a higher index in sentences D and F. In Argentina and Brazil, the experience of teaching seems to improve teachers' attitudes toward the WU item (the same happens also in Spain, but regarding only one sentence).

**Between women and men**

Table 4 shows the countries where we have found significant differences between the views of men and women for GE and WU items, and women have shown a more adequate attitude
than men have.

**Table 4. Significant differences in GE and WU items**

<table>
<thead>
<tr>
<th></th>
<th>More adequate attitude by women</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>S1 Group Brasil, Students (S1 and S2) Portugal, T2 Group Mexico</td>
</tr>
<tr>
<td>WU</td>
<td>Total sample Spain, Argentina and Mexico, S1 Group Spain, S2 Groups Spain, Argentina and Brasil; T1Group Spain</td>
</tr>
</tbody>
</table>

**On the responsibility of the school**

In terms of the items which address the issue of WU, sentence E refers to the responsibility of the school in this situation. This sentence has only appeared in the list of those who obtained the most positive attitudes in Brazil. Because the surveyed population corresponds to the educational sector, it seems important to emphasize which were the groups that showed significant differences in this sentence; namely:

- The S2 groups from Spain and Portugal, and the T2 Group from Spain, where more adequate attitudes was shown by the Non-Science sample.
- The S1 group from Portugal and T2 group from Spain, where men’s attitudes were more adequate than women’s.

These results demonstrate that only the younger students from Portugal, the senior students of Non-Science from Spain and Portugal, the in-service teachers of Non-Science (particularly men) believe that schools have not done enough to encourage women to choose Science courses, even though women are as capable as men in Science.

**CONCLUSIONS AND IMPLICATIONS**

The results show that some naïve views about the relationship between women and Science still persist nowadays; furthermore, it is also noteworthy that students and teachers display somewhat different views. Positive attitudes have been detected towards the following issues:

- Equity between women and men in terms of what it is needed to be a good scientist
- The fact that differences in the way scientists work in Science are due to personal differences, regardless of gender
- The fact that men and women work equally in Science
- The fact that the causes for the number of males scientists being much higher than women scientists ARE NOT related to men being stronger, faster and more brilliant or have no difficulties in concentrating on studies
- The reason for which there are far more male scientists than female scientists IS NOT that men seem to be more scientifically capable than women

Some negative attitudes towards these issues still persist, for example in terms of the perceived differences between male scientists and female scientists, regarding how they do Science because:

- They do not work the same way
- They do not have the same studies
- Men and women have not the same IQ
- Men and women are not equal; they depend on the job they do.

In the European countries which were part of the PIEARCTS Project, as well as in Brazil and Mexico, the surveys show more positive attitudes towards the idea that the reason why there are more male scientists than female scientists is NOT because men are more interested in Science than women. It is evident that in these countries, there is an increasing awareness of the fact that Science is a social activity and is, therefore, the predominant ideas in society are influenced by this awareness. Few differences were found between senior undergraduates and young students; this seems to show that higher education is not contributing to improve the students’ attitudes regarding Gender Equity and Women under-representation in Science.
However, future female and male teachers from some countries (Brazil, Colombia and Spain) seem to be aware that women under-representation in Science is not a natural matter, but a situation caused by an androcentrist culture which has been perpetuated for centuries. Accepting this fact is the first step towards promoting a change in this situation. Considering gender among the people in the educational area, it is possible to establish that women appear to be more aware than men of the fact that the relationship between women and Science is an unsolved issue. This is shown by the fact that the majority of the variables where differences have been significant between men and women, women are the ones who show more adequate attitudes. This is a positive sign because they can promote a change in attitude in the rest of the people they have an impact on (children, students, partners, etc.).

To conclude, we should engage in a serious and deep reflection about the role that schools have played in the reproduction of the distorted view of Science as neutral. The more positive attitudes about the responsibility of schools in having discouraged women from choosing Science courses have been shown by groups from Spain, Portugal and Brazil - which is a serious wake-up call for the rest of the American countries-, and mainly by young male students, male and female senior students and male and female teachers of Human and Social Sciences. It is striking to note that those more involved in Science education in primary schools were women, and in secondary schools and university it was Exact and Natural Sciences teachers.

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"SCIENTIFIC INQUIRY PRACTICES OF WORKSHOP EXPERTS FOR ELEMENTARY STUDENTS IN MEXICO"

Reyes-C Flor¹ and Garritz Andoni²
¹ Universidad Pedagógica Nacional, Unidad Ajusco, EDUCIEN
² Universidad Nacional Autónoma de México, Facultad de Química, Departamento de Física y Química Teórica

Abstract: In this research, we characterize Scientific Inquiry practices of workshop experts for elementary students in Mexico in a teaching-learning science programme that provides scholar science and mathematics activities directed to children guided by a set of Workshop Experts, whose role is to head the workshops.

To characterize scientific inquiry practices, for four selected workshop experts, a session with children was recorder and analysed using The National Science Foundation (1999) teacher inquiry indicator’s guide that look for special characteristics in the classroom.

This research shows that the Workshop Experts have evolved in their behaviour and actions, from a more participant and directive approach to an assessing and guiding role that involved listening and observing the student actions and interaction. The workshops experts aided with inquiry lesson materials and with a formation programme can produce a learning context that can be categorized by the indicators as inquiry based teaching and learning. It seem that with time, more formation’s phases and experience immersed in an inquiry programme, inquiry actions can be performed by a teacher with better results.

Keywords: Scientific inquiry learning, elementary school, science teaching, inquiry indicators, inquiry practices.

BACKGROUND, FRAMEWORK, AND PURPOSE

Scientific inquiry is a concept that was presented for the first time in 1910 by John Dewey; since that time different educators have use it. For example, Joseph Schwab (1960, 1966) was an influential voice in establishing the view of science education through inquiry. He suggested that teachers should present science as inquiry and that students should use inquiry to learn science subject matter. To achieve these changes, Schwab recommended that science teachers should look first to the laboratory and use experiments to lead, rather than to follow, the theoretical classroom phase of science teaching.

In 1996 the National Research Council (NRC) presented a specific definition of inquiry, in which teachers can and should promote the curiosity and the development of the students’ abilities regarding to inquiry. Inquiry is defined as:

The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as a comprehension of how scientists study the natural world (NRC, 1996: 23).
Anderson in 2007 emphasizes three inquiry subsections: scientific inquiry; inquiry learning; and inquiry teaching, explaining that if it is central to science learning then it must be central to teaching as well. This statement makes clear that there are three different subjects that can perform inquiry activities: scientists, the students and teachers.

In the last fifty years scientific inquiry has been a topic of interest in educational research mainly with the student as the principal subject but, according to Mac Neil and Krajcik (2008), there is a little amount of researches on the teachers’ practices in inquiry classrooms. This research aimed to characterize Scientific Inquiry practices of workshop experts for elementary students in Mexico in a teaching-learning science programme.

THE ROLE OF THE TEACHER IN THE SCIENCE INQUIRY CLASSROOM

A teacher, in order to guide an inquiry lesson must develop a robust capacity for pedagogical design, and the ability to put into practice a variety of personal and curricular resources to promote student learning. In Scientific Inquiry, the teacher’s role becomes less involved with direct teaching and more involved with modelling, guiding, facilitating, and continually assessing a collaborative student work. (NSF, 1999:82)

In an inquiry based teaching and learning the student and the teacher are expected to develop certain abilities related in each level to learning and teaching. The National Science Foundation (1999) adapted, form materials created by the Exploratorium institute for inquiry (2010), three different inquiry guides that look special characteristics in the classroom

1. What are the students doing? On-the-run reference guide to the nature of elementary science;
2. What is the teacher doing? The role of the teacher in the inquiry classroom;
3. How does the environment support inquiry? The social and emotional environment of the inquiry classroom.

Each one of them has an average of five activities and each activity present no less than three indicators.

The programme selected to performed this research is PAUTA (Programme Adopt a Talent: “Programa Adopta Un Talento”) created by the Mexican Academy of Sciences, in collaboration with the National Autonomous University of Mexico. This programme provides scholar science and mathematics workshops directed to children that are studying in elementary schools. In PAUTA there are Workshop Experts whose role is to head the workshops with students.

The programme, in a constructivist learning and teaching approach, pursues that children explore and analyse different phenomena by means of activities (Garcia et al, 2010), specifically designed to learn science by developing their scientific abilities. The activities, as was recommended by Schwab (1960), are arranged in sequences of the experimental type that allow students to review the concepts involved in a specific problem or question on different contexts.

Each activity has a document “expert workshop guide” with specific suggestions of actions and instructions that the teacher must perform to promote the children’s development of science abilities in an inquiry activity context. According Martin-Hansen (2002) categories of
inquiry, this is guided inquiry, in which the question to be solved is presented by the teacher and the student may decide how to approach it.

METHODS

Taking into account that the activities developed by the workshop experts are crucial tools with which teachers engage students in science as inquiry (Forbes & Davies, 2010) and by extension the pedagogical activities involved, the activity called “Floating and sinking” was selected to be examined; in this activity the children analyze how different objects can or cannot float.

The data collection was made primarily by videotaping the activity sessions of four workshop experts, in two main phases: the first semesters of 2008 and 2010. This four workshop experts were selected based on a previous research that aimed to document the Pedagogical Content Knowledge of the experts with a Content Representation frame of Loughran et al. (2004) that was applied all of the nine workshop experts. The selection of these four experts was made taking the next bases: That they wave participated in the previous research, the permanence in the programme, and finally the bachelor speciality: one was mathematic, one ethnology and two biologists.

The selection of the data collection corresponds to the two implementation of the same workshop, with the same four workshop experts, with students (from 6 to 13 years old) in the first year in the programme. It is important to mention that the programme have groups of student arranged by the levels that they have taken in the programme rather than the age that they have. The first time “Floating and sinking” took place was in 2008 and the next implementation with these characteristics was until 2010.

One video camera was used to film the actions of the workshop expert, and since two of them conducted each session, audio records were made for each one. For the analysis, the videotapes were coded with the indicators related to the activities in each one of the guides to observe inquiry activities. The present results have more emphasis on the analysis of the workshop experts’ inquiry indicators.

RESULTS

We have found significant differences between the two periods (2008 and 2010). Regarding to the “Teachers Model Behaviors and Skills”, in the 2010 workshop experts posse more scenarios to enhance that the student take control and responsibility on their action, whereas in the 2008 workshop experts did not promote this actions.

A clear evolution in the 2008 and the 2010 were fund related to “Teachers Use Multiple Means of Assessment” and “Teachers Act as Facilitators”, mainly the workshop experts in 2010 listen more often and talk or direct much less to the student, the conversation held in the classroom in 2010 evidence that the Expert is listening carefully to the children and using that as basic information to express the next idea or comment only if necessary.

2010 Student 1: We weight the wooden cylinder, the wooden cylinder floats but it was lighter. And the spoon, [the metal spoon] well the spoon is lighter than the cylinder. But, the cylinder is…well…
Workshop expert: ¿Which cylinder? [The metal one or the wooden one]
Student 2: The metal spoon is heavier; it is one gram heavier than the wooden cylinder
Student 1: But the cylinder was heavier, was not it? Or was it? [Student2 y Student3 confirm that the cylinder was heavier]
The cylinder was heavier than the spoon, it [the cylinder] did not sink and the spoon did.
Workshop expert: What can you say about this?
Student 1: Well, I think it is the material.

Whereas in 2008 there are several interactions that clearly show that the expert did no listen to the student, that they try to impose a particular question that is different than the actual interest of the students, and that they show up to student discussion an posse a new question, before listening to what they have been arguing.

2008 Workshop expert: Which one of the objects that you have is going to sink?
Student 1: The iron one
Workshop expert: that is right the metal cylinder
Workshop expert: Which other?
Workshop expert: over here they said that the wooden cylinder. Why do you believe that this one is going to sink? It is because it is heavy, right?

Also the Workshop Experts in 2010 started to suggest new things to look at and try, and encourage further experimentation and thinking in their students but in 2008 they followed the facilitator guide in a more rigid way.

CONCLUSIONS AND IMPLICATIONS

This research shows that the Workshop Experts have evolved in their behaviour and actions, from a more participant and directive approach to an assessing and guiding role that involved listening and observing the student actions and interaction. In this guiding role they suggest more often new things to look at and try, and thinking: This could be related to the novelty of the activities and the use of inquiry based activities in 2008 and to the expertise gained though the coupled of year in the programme. It seem that with time, more formation and experience immersed in an inquiry programme, inquiry actions can be performed by teacher with more emphasis and probably with more clarity on the goal pursued in each one.

The workshops experts aided with inquiry lesson materials and their regular formation courses can produce a learning context that can be categorized by the indicators as Inquiry based teaching and learning.

As a corollary all changes involved a considerable amount of energy, work and commitment; specially changing the pedagogical skills, but building them is equally important to the construction of content knowledge, particularly as a means of providing student-centred learning experiences.

And in a metacognitive level, to improve the science teaching-learning process, it is important to document what happened in an actual Workshop, how Workshop Experts establish didactic units with these characteristics, and how they promote the development of scientific abilities in their students.

ACKNOWLEDGEMENTS

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EPISTEMIC STYLES OF THINKING OF PRE-SERVICE CHEMISTRY AND PHYSICS TEACHERS

Norman Riehs and Stefan Rumann

University of Duisburg-Essen, Germany

Abstract: Theoretical works of different authors lead to the assumption that the subject of study influences the epistemological stances of students. Regarding pre-service teachers, views on aspects of Nature of Science can differ between biology, physics, and chemistry teachers. Due to the lack of quantitative instruments examining epistemological stances in respect of scientific realism, a questionnaire was developed and carried out in a pilot study to pre-service secondary physics and chemistry teachers in a pilot study (students and Ph.D. students; n = 41).

The results of the pilot study are insightful. The chosen items are comprehensible and show a good reliability. The size of the sample admits of item response theory (IRT) calibration, showing the items fit the model adequately. As a first result, the difference of the degree of scientific realism of pre-service chemistry and physics teachers is significant and the effect size is huge. Chemistry teachers tend more to scientific realism than physics teachers. The degree of scientific realism scale might be useful for explaining the classroom handling with models and modelling of science teachers by epistemological positions.

Keywords: Nature of Science, Philosophy of Science, Secondary Teacher Education, Chemistry, Physics

THEORETICAL FRAMEWORK

In the past decades philosophers of science have argued whether or not philosophical stances of scientists influence their work (see McMullin, 1984, Scerri, 2000; Elfin et al., 1999). Additionally, the relationship between specific subjects and epistemic positions has not yet been pointed out. But despite this lack of quantitative research one can find some evidence for different 'styles of thinking' in the history of science. This concept was first developed in the early 20th century by Ludwig Fleck and continued by Alistair Crombie and Ian Hacking (see Bensauda-Vincent, 2009). Bensauda-Vincent used the term 'styles of thinking' for an analysis of the chemists' approach to science. In a similar way Eisvogel (1994) examined the character of a theory as either 'realistic' or 'instrumentalistic'. These characters form the thinking among the community of scientists using these theories.

Independent of the question whether there is an impact of philosophical stances on applied scientists’ thinking and acting, there is much more interest for research in science education regarding the relationship of epistemology of science teachers and their handling of models and students' beliefs in educational situations.

In spite of increasing calls to implement Nature of Science (NoS) in the science curricula (Lederman et al., 2002), quantitative studies to point out science teachers’ epistemic stances and their influence on aspect of pedagogical content knowledge (PCK) have not yet been carried out.

The first criticism on stated NoS-tenets in science education was given by Alters (1997), examining the difficulties of philosophers and scientists with the goals of NoS-programs.
Although there was a dispute about the design of Alters’ survey, the criticism on stated tenets cannot be overlooked: philosophy does not give absolute and final answers. In contrast Lederman et al. (2002) argued for the emergence of consensus on the tenets with increasing the level of generality. This position can also be found in earlier works, like Abd-El-Khalick et al. (1998). But following up the path of generality regarding epistemic assumptions leads to the meta-level of objectivity and subjectivity of science, or—in general parlance—to the question whether an objective and independent outer world exists or not. Basic assumptions determine the stances in the lower levels, e.g. one cannot be sure about the factual existence of non-observable entities without claiming a world independent of the observer.

To respect the different views on the world it is necessary to change the tenets into open questions, which was first suggested by Clough. For instance, instead of teaching the tenet “scientific knowledge is tentative” one should rather discuss with the students the question “in what sense is scientific knowledge tentative?” (Clough, 2007).

This study is concerned with the question whether or not the styles of thinking of chemistry and physics student differ in respect of the degree of scientific realism. It is supposed that a more anti-realistic epistemic position of student teachers regarding the reference of scientific theories and entities allows them easily to switch between students preconceptions driven by common-sense-realism and mature scientific concepts.

Due to some evidence from the literature (e.g. Scerri, 2000; Bensaude-Vincent, 2009), it is expected that the more anti-realistic stances will be found within the physics teachers group, while the chemistry teachers share a more realistic view on the world.

**METHODS**

To examine the epistemological positions of chemistry and physics student teachers a questionnaire was developed and carried out in a pilot study to measure the degree of scientific realism. The theoretical framework for the categorisation of the different thinking styles was based on philosophy of science literature (Hacking, 1983; Van Fraassen, 1980; Putnam, 1975).

The idea of a ‘degree of scientific realism’ scale bases on the assumption, that each position in philosophy of science has its own authority, but all positions share a more or less realistic approach. The aim of the questionnaire is to examine a one-dimensional scale to describe the degree of scientific realism of science teachers.

20 statements about scientific realism or anti-realism were collected from philosophy of science literature, followed by a translation into non-philosophical language. Pilot study participants’ agreement regarding the given statements was measured by a four-step Likert-type scale from “I totally agree” to “I totally disagree”. The statements derived from philosophy of science literature were verified in terms of the comprehensibility through the participants’ option to leave the item out, if they did not understand the arguments’ meaning.

**RESULTS**

The pilot study was conducted with a sample of 41 pre-service chemistry and physics teachers, 20 student teachers at the end of their study and 21 Ph.D. students of science education. The respondents’ demographic data is presented in table 1.
Following Linacre (1994) the sample size suffices for partial credit model (PCM) item calibration, which was made with R-statistics. The analysis examined a mean item-infit-MNSQ of 0.99 (S.D.: 0.25; range: 0.56–1.43) and a mean item-outfit-MNSQ of 1.04 (S.D.: 0.26; range: 0.56–1.50). The values show the productivity for measurement (Linacre, 2002). The PCM item measures are sufficiently distributed with mean modelled standard errors of 0.21 (S.D.: 0.02). The items' difficulty spread is between −1.81 and 1.19 logits, the spread of respondents’ measures spans from −2.24 to 0.85 logits on the person–item map. In the further analysis the PCM measures will be used instead of the persons' raw scores.

A Shapiro-Wilk test (Shapiro & Wilk, 1965) verifies the participants' measures come from a normally distributed population. The thesis of a non-normal distribution is refused (p = 0.45). Further tests including subgroups “physics” and “chemistry” show quite similar results (0.42 < p < 0.49).

One major finding is the significant difference in the degree of scientific realism between the subgroups of pre-service chemistry and physics teachers (table 2). The effect size of the difference is huge (Cohen's d = 1.24).

### Table 2: Degree of scientific realism mean measures of pre-service chemistry and physics teachers.

<table>
<thead>
<tr>
<th>Subject of study</th>
<th>Measure</th>
<th>S.D.</th>
<th>T</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>0.13</td>
<td>0.68</td>
<td>3.90</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Physics</td>
<td>-0.80</td>
<td>0.81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONCLUSION & IMPLICATIONS**

There has not been collected enough data yet for verified conclusions. Nevertheless, if Nature of Science should be part of science education, one has to rethink teachers' education in respect to the philosophy of science. The very creating of new chapters for textbooks and enlarging or substituting of curricula is not an adequate form of implementing the philosophical area of Nature of Science in secondary school education. The development of a deeper understanding of the philosophical debate might be a key skill for science teachers in
respect of analysing and understanding students’ misconceptions. To answer this question, the questionnaire will be used with a larger sample, combined with quantitative instruments to measure the use of models in classroom contexts.

**BIBLIOGRAPHY**


NOS IDEAS AS CONTEXTUALIZED IN THE PRESENT SCIENCE: NANOMODELLING AS AN EXAMPLE

Suvi Tala

Department of Physics, University of Helsinki

Abstract: Understanding nature of science (NOS) is widely considered an important educational objective and views of NOS are closely linked to science teaching and learning. Nowadays, there is a kind of consensus about the content of NOS teaching, which is a result of analyses in educational, philosophical, sociological and historical research. This consensus content is listed as statements of science, which students are supposed to understand during their education. Research in science education has anyway frequently shown that students have not reached sufficient understanding about NOS. The reason is proposed to be that the formal statements about nature of science and scientific knowledge can really be understood only as contextualized in the practices of science. To contextualize NOS statements in the actual practices of science in contemporary education, we need empirical studies, which are performed in co-operation with scientists themselves. This is such a study; by employing both a questionnaire and interview as research methods this study reveals how practicing nanoscientists perceive the nature of science developed in their own research projects. Many of the general NOS statements arise as contextualized in discussion with practicing scientists; deepening thereby our understanding about the core of NOS, science and scientific knowledge, for science education. The results can be used also as such, as a basis of reflective stories of recent science for contextualized NOS teaching – and the method developed can be used as a basis of “interview a scientist” tasks and in further research. For the contextualized NOS education suggested in this paper, we would need several similar empirical studies.

Keywords: contextualized NOS, NOS education, scientific modeling, contextualized interview study

NOS CAN BE UNDERSTOOD AS CONTEXTUALIZED IN EXAMPLES OF SCIENTIFIC RESEARCH

Developing an adequate understanding regarding the nature of science (NOS) in students has been widely seen at the core of the scientific literacy (Matthews 1998, McComas & Olson 1998). Indeed, understanding the nature and the basis of what one is studying encompasses coherent conceptualization and conceptual understanding (Osborne et al. 2003, Sandoval 2005) – the traditionally valued goal of science education. Understanding about science and its nature increases then one’s interest in science and science classes. At the moment, there is a kind of consensus on what the NOS understanding does include; this is a result of analyses of educational, philosophical, sociological and historical research and discussion (Lederman et al. 2002, Mathews 1998, McComas & Olson 1998, Osborne et al. 2003). Such NOS content is defined by listing statements of nature of science, which students are supposed to learn during their education – or as family resemblances (Irzik & Nola 2010). Because science is rich and dynamic endeavour and scientific disciplines are quite varied, the NOS statements are quite general descriptions about “science”. For example, the statements “models and modelling have important roles in science” and “science has an impact on technology and technology has a role in science” appear frequently on the lists of NOS statements. These
general NOS statements can be interpreted in a numerous ways: for example, the viewpoints guiding scientists’ research practices is the viewpoint supporting their concept building and the understanding about the scientific process.

Irrespective of the century-long history of the place of NOS in many curricula (Lederman et al. 2002, McComas & Olson 1998, Mathews 1998), the NOS objectives – learning the NOS statements for understanding – have not been reached (see e.g. Clough 2011, Lederman et al. 2002, McComas & Olson 1998, Osborne et al. 2003 and the references therein). The situation is considered to be the result of the taken-for-granted explicit and abstract view towards NOS (Lederman et al. 2002, Sandoval 2005). One can understand the abstract NOS themes only as contextualized into different contexts of scientific research; but students do not know what scientists do while working. Thus, students have to become familiar with authentic examples of scientific research, which provides them with contexts to understand the abstract NOS themes. Research indicates that by this kind of reflective – or contextualized – approach to NOS education, good results can be reached (Clough 2011, Hanuscin, Akerson & Phillipson-Mower 2006, Matthews 1998, Sandoval 2005). Moreover, when opening this kind an insight to the production of scientific knowledge, NOS teaching increases the coherence of science education. Thus, what is needed to enhance NOS understanding in science education is concretizing by examples what the NOS statements mean in the practices of science in different fields of research.

At the moment there are rich examples of contextualization in historical stories of science (e.g. Clough 2011). This study suggests that in order to support understanding about the present science for literacy, which means an ability to apply one’s NOS understanding in public discussion about contemporary science, also examples of what does NOS ideas mean in the context of contemporary science need to be addressed. Discussing the present science in science classes may also increase students’ motivation to study NOS and science in general. Anyway there is a lack of empirical studies about the nature of science in the contemporary knowledge construction practices of science and scientists’ ideas about the nature of science they do. Thus, here is provided such an empirical study, as an exemplary case, a study about the nature of science as seen through the practices of nanoscience. The study examined how the viewpoints opened by NOS statements to scientific knowledge construction and justification may do appear in the nanoscientists’ views. The contextualized method was developed and employed in order to increase the validity: simple, the scientists were not asked what nice ideas they would like to be told in education about the nature of their field, but instead to encourage them to tell about the nature of their field at the practical level. Thus, the study provides exemplary cases, by which to understand the NOS themes in the practices of science. The abstract NOS ideas can be better understood by listening to such exemplary voices in the mixed choir of scientists.

**NOS LISTS AND DIFFERENT METHODS OF SCIENCE**

The nature of science is in the lists of NOS ideas defined from the viewpoint, how natural science differs from the humanities, for example: thus, the general definitions of science, such as listed by Merton norms (objectivity etc.) or counter-norms, are not listed. The table 1 presents a summary of the typical NOS ideas appearing on NOS lists, as it was summarized on basis of previous comparisons and studies (Hanuscin, Akerson & Phillipson-Mower 2006, Lederman et al. 2002, McComas & Olson 1998, Osborne et al. 2003, Sandoval 2005).
The natural sciences become first and foremost defined by the objectives adopted and methods employed: The shared motive of the different natural scientists is an attempt to explain “natural” phenomena (NOS theme) taking place in natural and man-made environments. In that is used a variety of methods (NOS theme). Indeed, the nature of scientists’ knowledge building and the nature of the knowledge produced in that are strongly figured out by the methods used. The methodologies employed in revealing reality can be divided into theoreticians’, modellers’ and experimenters’ fields of business; the different practitioners’ can see the nature of science in a quite similar way but they explain the nature of this enterprise from different viewpoints. In science studies, most analysed are the theoreticians’ viewpoints and the viewpoints opened by theory-oriented approaches. For about a half decade attention has been increasingly paid also on experimentation and experimenters’ viewpoints (see Tala 2009 and references therein). Only recently, when modelling is noticed to be rapidly growing, as the third method of science beside the traditional ones, there has been a growing interest toward it in science studies (e.g. Humphreys 2004, Morrison and Morgan 1999). Then has been noticed also the lack of empirical studies considering the practices of modelling and viewpoints opened by practising modellers. Because modelling is nowadays widely used by side of the traditional methods, modelling will probably be soon described by more details also in the lists of NOS statements (like the traditional methods are in the present lists).

In science education models are typically seen as deduced from theories and modelling as a direct continuation of theorizing, which reflects the situation in the science studies couple of decades ago. The discussion about models in science studies during the last decades in science studies, has given them a variety of roles, but it have been generally agreed that models are representations (see e.g., Giere 2004, Hughes 1997, Morrison and Morgan 1999): we gain knowledge from models because they represent target objects in the world in some relevant respects. Moreover, recent studies (e.g., Galison 1997, Hacking 1983, Humphreys 2004, Morrison & Morgan 1999) indicate that the perspective on the practices of science provides a different approach to models and modelling; models and modelling have been suggested to have quite an independent role as mediators between different methods (e.g. Morrison & Morgan 1999). These questions of how the relations between reality and the different methods employed are constructed are important for scientists (Hacking 1983; Galison 1997) – and it is important for science education as a base of the knowledge taught. Thus, in order to understand better the nature of this enterprise called science, it is worth for to ask also practising scientists how those links with reality – or realities – and different methods are constructed in their knowledge building.

Fig1: A list of the typical NOS objectives

- “science is an attempt to explain natural phenomena”
- “there is no one scientific method”, but “a variety of scientific methods is employed”
- “models and modelling have important roles in science”
- “science has an impact on technology and technology has a role in science”
- “the creative role of human beings, societies and cultures in constructing science”
- “the historical development of science”
- “the impact of science on cultures and societies”
- “science is essentially a global phenomenon having both global and local influence”
- “certainty or tentativity of scientific knowledge”
- “theory-ladenness of experimentation”
METHODS: QUESTIONNAIRE AND INTERVIEWS AS CONTEXTUALIZED IN THE INTERVIEWERS’ PROJECTS

The phenomenological case study (Tala 2011) taken here as an example, discovers the conceptions and beliefs of nature of science guiding the knowledge building practices of nanoscientists – and teaching these practices in their doctoral education. The informants are Finnish material physicists studying nanophenomena by realistic simulations, 5 experts (E) and 5 apprentices (PhDs; A). The research was planned in co-operation between researchers’ in science education, in physics and in philosophy. To get a broader view, the views of the informants were studied by multidimensional methods: The informants answered a written questionnaire about their epistemological and methodological views as contextualized in their on-going projects. The questionnaire was planned on basis of understanding opened by recent science studies and familiarity with the practices of physics – this basis also helped in contextualizing the study in the interviewers’ research projects.

The NOS views are many time tested by asking scientists questions at general level, asking such questions as “what you think are the most important points every citizen should know about the nature of science?” or “do you think models play a role in science?” Anyway, many physicists do not like to speak “philosophically”: although they deal with contextualized philosophical questions in their work, they do not need to think the philosophical question at the general, explicit level while working. Indeed, there is always a possibility that the interviewer and the interviewee understood the general terms in different ways. Moreover, when the questions or answers are contextualized in the informants’ concrete doings, in this case in their on-going research projects, they may tell what really guides their action and decision making, rather than what theoretical lessons they may have learned about it, for example.

The informants were interviewed one by one; the interviews were semi-structured on the basis of the interviewees’ responses to the questionnaire and their articles they sent in advance. It was noticed that the same viewpoints emerged over and over again in the responses of the internationally successful scientists, increasing the reliability of the results. The transcript interviews together with the responses to the questionnaire were analyzed by qualitative content analysis: the NOS statements formed the categories used and then also the links existing between the contextualized NOS statements were noticed. The interviewees checked the analysis; as a consequence, the interpretations became corrected according to the interviewers’ requests (validity).

RESULTS: NOS AS ONTEXTUALIZED THROUGH THE VIEWS OF PRACTISING MODELERS

Many of the shared NOS ideas arise in the interviews with practicing nanomodellers, as contextualized in their projects (particular definitions of NOS). This kind of contextual approach also clarifies how the NOS statements are closely connected to each others in authentic research processes, which will be seen in the following examples picked out from the results. Every field of science highlight and explain more some NOS ideas than others. Because the modellers’ views are under scrutiny in the following, the statements ‘science has an impact on technology and technology has a role in science’ and ‘models and modelling have important roles in science’ become naturally emphasized.

Basically, the expert nanomodellers define their field of research to be “application-motivated basic research” (E1), which they explained means that possible applications – potential technological, financial and human needs – make selections between the possible research
projects before launching one. They do not develop commercial nano-products\(^1\), but for financial reasons, for example, those interesting research topics are selected, which have “relevance of some practice” (E1). In particularly an apprentice reasoned his research by “tree words: nano, bio, medi” (A1). The interviews told that they clearly refer to the applications, when writing the applications for financial funding or introductory parts of their publications or telling about their research for general public. At the same time nanoapplications, impose new ethical problems – for example, the interactions of nanoparticles in a human body, are not known yet – and become limited on this basis. Nevertheless, the interviewers highlighted that the applications “are [only] in the back of my mind” (E2) and thus they consider that they do not need to consider the ethical questions related to the possible applications. Thus this strive for applications contextualizes in a way not only the NOS statement ‘science has an impact on technology’ but also the pair of NOS statements ‘science is a product of a large social and cultural settings’ and ‘science has an impact on cultures and societies’.

Furthermore, technology provides an access to the artefactual nanoworld: when working, modellers sit mostly by their computers. No one of the interviewers failed to mention how computational and technological abilities, namely the capability of computers figures out what can be studied by nanomodelling, and how. The fundamental reason is concentrated in the following novice’s response: “the whole of molecular dynamics [the favoured method] would not function if the frequently repeated calculations were not made as simple as possible and quick for the computer to calculate” (A2). As a consequence, what can be studied and how it is studied in nanophysics is strongly figured out by technological limits, namely by the capability of computers. Nowadays, the length of the objects simulated at the nanolevel has to be limited to some nanometers, or, alternatively, an event on the surface seen by a nagged eye can typically be simulated only for a nanosecond. Nanoscientists are creative (NOS theme) when discovering the nanoworld within these limitations of time and length scale.

But the modelling technology, and especially computational power, is a rapidly developing field, advanced as collaboration between scientists and technologists. A century ago, nanoscientists did not have the kind of inside to the reality of physics they develop and maintain nowadays. The development is not going to stop here; with a great pleasure, the interviewees described what they can study in the nanoworld, when computers develop on. In this way, also the NOS theme ‘the historical development of scientific knowledge’, is easier to understand by considering a concrete development of technological capability.

As a new field of study, nanoscience is a rich example of how science develops by correcting and extending the previously “known” and the scope of this knowledge: at the time, when the most of the basic scientific content presented in the high school text books where discovered, the nanoworld was entirely unexplored.\(^2\) In due to the dreams of the future development, in

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\(^1\) The applications of nanotechnoscience, ranging from smart drugs to environmental materials with extraordinary properties and to fast processing, ultra thin, flexible machines (see also, Rosei 2004), improve many ordinary artefacts.

\(^2\) The recent history explains also the contemporary science: For example, scientists did not have access to the nanoworld and nanophenomena before the invention of the scanning tunnelling microscope by Gerd Binnig and Heinrich Rohrer at IBM Zurich Research Laboratory, for which they received the Nobel prize in physics in 1986. The scanning tunnelling microscope is an instrument for imaging surfaces at the atomic level, which is nowadays an everyday device in laboratories, it is employed also by those interviewers who have experience of working on the experimental side of the field. Additionally, the discovery of fullerenes in 1985 by Harry Kroto, Richard Smalley, and Robert Curl (Nobel prize in chemistry) was important for the foundation of nanoscientific research.
addition to the development of computers’ calculation power allowing the increase in the size and time of the simulations, the modellers mentioned also their expectations concerning the development of experimental technology: according to a novice, at best this would mean the “real-time measuring equipment” (A3) (like a video camera). At the moment they observe the situation like in-direct still photos and numbers linked to those. But then, “these models are naturally quite simple, and thus do not represent a system very well” (A2). The more advanced a interviewed scientist is the more (s)he seems to highlight the role of technology figuring out the scientific modelling. Then an expert pointed out: “when a physical template [the mathematical formulation of physical law] is fitted to a computer, it becomes a kind of new theory...[it] is never the same as the original physical template which provided the starting point.” (E3) In consequence, the NOS idea ‘science has an impact on technology and technology has a role in science’ is quite a deep one: the science-technology relationship should be understood to strongly figure out both activities to the extend it alters the basis of knowing in both fields, the epistemologies employed. Finally, even the interviewers’ modelling is called “the realistic modelling”, such successful modelling is guided by an instrumental view towards models and modelling, as seen in the following.

In nanomodelling is generated new knowledge of the previously unknown phenomena under limited possibility for experimentation: this is generative modelling. In practice the modellers make a coarse model, which then become fitted with experimentation. In that fitting, modelling figures out the experimentation from the planning of the experimental settings to the interpretation of them. But then it is a two-way process: also modelling becomes fitted to experimentation, and validated by this fitting with experimentation. This is what the NOS statements ‘the empirical base of science’ and ‘experimentation is theory-laden’ mean in the case of the practices of nanophysics. Nevertheless, even the development of modelling and experimentation take place in close interaction, those remain as separate approaches. The modellers emphasize this to the extent that “a model doesn’t care about the actual conditions or claims that it explains them, since the only important property of a model is its functionality” (A4). In consequence, the modelling, which mediates between theory and experimentation, advance both limited traditional methods, experimentation and theorizing, staying anyway an independent approach.

It was noticed in this study that young scientists adopt these above introduced contextualized views about NOS in their field during their education. For example, young modellers start to understand, how technology both enables and limits research projects, and how it figures out the scientific knowledge construction and justification processes. The results indicate that the longer a successful young modeller has worked for a research group, the nearer her/his contextualized NOS view are the elder researchers’ views. Thus, the view opened by this empirical study seems to reflect the view, which guides scientists in successful knowledge building. As such, it deepens our views about the nature of science, by the viewpoints supporting conceptual understanding and understanding about the scientific process.

CONCLUSIONS AND IMPLICATIONS

This study showed how many of the general NOS notions arise as contextualized in discussion with practicing scientists. Understanding the practitioners’ contextualized NOS views deepens our view to science for science education. Especially, the results of this empirical study extend recent views of the quickly developing nature and roles of modelling, simulation and modelling technology in science – and theirs relation to experimentation and theories. In science classes the understanding of the nature of science listed as NOS statements, can be improved by providing examples of contemporary science, constructed on the basis of empirical studies like this.
The empirical base provided by the study on nanomodellers’ views can be used as such, for example, as picking up case stories from the data, providing concrete meaning into the abstract and general NOS notions in science education. Because the study was contextualized in the interviewers’ research projects, there in the interview data exist many practical examples of the kind of knowledge building described here and, because those are in the field of realistic modelling, many of them could be introduced also at the level of compulsory education as examples of this kind of way of thinking. In order to make NOS teaching by contextualization effective, the stories and their relation to the school science activities have to be also discussed in science classes; good learning results have been reached by reflective approaches to NOS, and by approaches combining the implicit and explicit NOS teaching (Hanuscin, Akerson & Phillipson-Mower 2006, Sandoval 2005). Indeed, different fields of science highlight different viewpoints to the nature of science. In order to extend the base of examples in contemporary science, we need more empirical studies performed on different fields of science.

REFERENCES


TEACHERS’ CONCEPTIONS ON NATURE OF SCIENCE: STRENGTHS, WEAKNESSES AND INFLUENCE OF TEACHING PRACTICE

Ángel Vázquez-Alonso1, Maria-Antonia Manassero-Mas2, Antoni Bennassar-Roig3 and Antonio García-Carmona4

1Department of Applied Pedagogy and Educational Psychology. University of Balearic Islands, Spain, angel.vazquez@uib.es
2Department of Psychology. University of Balearic Islands, Spain, ma.manassero@uib.es
3Department of Biology. University of Balearic Islands, Spain, abennassar@uib.es
4Department of Didactic of Science. University of Seville, Spain, garcia-carmona@us.es

Abstract: The understanding of the nature of science (NoS) is assessed in a large sample of high-school science teachers, which encompasses pre-service and in-service teachers. The teachers anonymously completed 15 questions, whose responses are scaled into a set of attitudinal indices. The results show global neutral attitudes of teachers, and the detailed examination of indices identifies the teachers’ strengths and weaknesses beliefs; unlike other studies, which provide a negative profile of teacher understanding, the diagnosis that emerges is more complex, as appropriate beliefs coexist with some inappropriate beliefs; however, the overall assessment must be negative, because the science teachers should exhibit better understanding of these issues. The pre-service science teachers do not significantly differ from in-service science teachers, so the evidence is not decisive to claim that science teaching practice contributes to improve NoS understanding. These results suggest the urgent need to update initial and in-service training for science teachers, to improve their understanding of NoS topics in science curricula, and thus improve science teaching. The implications of the methodology and results for the research, teacher training, and teaching of nature of science and technology issues are discussed.

Keywords: nature of science, science-technology-society, evaluation of conceptions, teachers’ thinking, teacher training.

BACKGROUND, FRAMEWORK, AND PURPOSE

The nature of science (NoS) is widely accepted today as an undisputable target of science education to achieve an authentic scientific and technological literacy for all. Understanding NoS is deemed the most innovative goal of science education and an important component of scientific literacy for all. Thus, the school science curriculum should incorporate and the teachers should teach them (e.g., Abd-El-Khalick & Lederman, 2000; Lederman, 1992).

Research on NoS consistently reports that pre-service and in-service science teachers’ understanding of NoS issues widely deviate from the modern views of science, as the history, philosophy, and sociology of science and technology studies have currently set up. Rather it seems close to traditional, positivist (logical empiricist), and idealistic views of S&T, which are similar to the list of myths (McComas, 1996), or contrary to the list of consensuses (Bartholomew, Osborne & Ratcliffe, 2004). Many of the research show that teachers understand science as a static body of knowledge (thus, true and unchangeable), or as a process of discovering what is out there, not as a human process of inventing explanations, and so on (among others, see a recent revision of state of art in Lederman, 2007).
Teachers’ NoS beliefs are central for science education, because they decisively influence their teaching practices within the classrooms. For instance, teachers who believe that science is an accumulation of knowledge tend to do experiments by following the textbook instructions and getting the right answers; in contrast, teachers who believe that science changes are more likely to encourage students’ discussions (Smith & Scharmann, 1999). Besides, some studies pointed out that teachers with adequate NoS understanding do not automatically and necessarily teach NoS issues into classroom (Lederman, 2007). Although there are many factors involved in the decisions to teach NoS, in general, teachers lack relevant pedagogical skills to this aim. Further, research points out that some teaching practices are key to adequately address curriculum NoS issues: planning, designing and assessing the NoS contents, supply explicit adequate NoS concepts to learners, and providing general reflection and coherence between NoS tenets and the representations of science and technology within the classroom (Lederman, 2007).

Rationale

Scarc research on teachers’ conceptions about NoS has been focused on non-Anglo, in-service teachers until recently. So this paper draws data from an international cooperative investigation (Iberian-American Project of Evaluation of Attitudes Related to Science, Technology and Society, Spanish acronym PIEARCTS) that diagnose the NoS beliefs across seven Iberian-American Spanish and Portuguese-speaking countries. This paper presents the results of the application of the new PIEARCTS methodology to assess the NoS conceptions of large teacher sample that include pre-service and in-service high-school science teachers. The NoS conceptions are posed here from a wide perspective that includes internal aspects of science (philosophy and sociology of science) and external aspects of science (relationships of science with technology and society). The paper search empirical answers to the questions: Which are the strengths and weaknesses of teachers thinking on NoS? Do practitioner science teachers’ understand NoS better or worst than their pre-service counterpart?

Methods

Sample

The participants are 613 high-school science teachers, about one third (32%) in-service teachers and two third (68%) pre-service teachers. pre-service teachers in Spain are university graduate students in STEM specialties (physics, chemistry, biology…), who are involved in a postgraduate diploma in science education to be credited as prospective teachers (without educational experience); the in-service teachers are practitioner teachers. Their age range from 23 to 63 years and the sample splits approximately in equal halves by sex (52% men).

Instrument

The Questionnaire of Opinions on Science, Technology and Society (Spanish acronym, COCTS) is an adaptation into Spanish language and culture of the VOSTS and TBA-STS (Aikenhead & Ryan, 1992; Rubba, Schoneweg & Harkness, 1996). The COCTS is an empirically developed pool of 100 multiple-choice items, which inherits the credit of VOSTS and TBA-STS, as one of the best paper and pencil instruments to evaluate NoS&T beliefs (the empirical development of items warrants the item validity). All items display a common format: the stem presents a specific NoS issue, using a non-technical, familiar and simple language. A changeable number of sentences, each labelled with a letter A, B, C…, follow the stem; each sentence states a rationale position (belief) on the stem issue (Vázquez, Manassero & Acevedo, 2006).

The research team consensually selected 30 items that were distributed into two 15-item paper and pencil research booklets (F1 and F2; see table below), which meet a balanced coverage of
the different issues. Each participant answered one randomly assigned form (F1 or F2), with roughly a half of the participants answering the Form 1 (309), and the Form 2 (304).

Table 1. Labels of the questions included in the two questionnaire forms (Form 1 and Form 2) across the structural dimensions of NoS issues. A short description of the question issue follows each key number.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Form 1 Items (key / issue)</th>
<th>Form 2 Items (key / issue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Definition of S&amp;T</td>
<td>F1_10111 science</td>
<td>F2_10211 technology</td>
</tr>
<tr>
<td></td>
<td>F1_10411 interdependence</td>
<td>F2_10421 interdependence quality of life</td>
</tr>
<tr>
<td>b) STS Interactions in S&amp;T</td>
<td>F1_30111 STS interaction</td>
<td>F2_20211 industry</td>
</tr>
<tr>
<td></td>
<td>F1_20141 country’s government policies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F1_20411 ethics</td>
<td>F2_20511 educational institutions</td>
</tr>
<tr>
<td></td>
<td>F1_40161 social responsibility contamination</td>
<td>F2_40131 social responsibility information</td>
</tr>
<tr>
<td></td>
<td>F1_40221 moral decisions</td>
<td>F2_40211 social decisions</td>
</tr>
<tr>
<td></td>
<td>F1_40531 life welfare</td>
<td>F2_40421 Application to daily life</td>
</tr>
<tr>
<td></td>
<td>F1_60111 motivations</td>
<td>F2_50111 union two cultures</td>
</tr>
<tr>
<td>Internal Sociology of science</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F1_60611 women under representation</td>
<td>F2_70211 scientific decisions</td>
</tr>
<tr>
<td></td>
<td>F1_70231 consensus decisions</td>
<td>F2_70711 national influences</td>
</tr>
<tr>
<td></td>
<td>F1_80131 advantages for society</td>
<td></td>
</tr>
<tr>
<td>c) Epistemology</td>
<td>F1_90211 scientific models</td>
<td>F2_90111 observations</td>
</tr>
<tr>
<td></td>
<td>F1_90411 tentativeness</td>
<td>F2_90311 classification schemes</td>
</tr>
<tr>
<td></td>
<td>F1_90621 scientific method</td>
<td>F2_90521 role of assumptions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F2_91011 epistemological status</td>
</tr>
</tbody>
</table>

Procedures

The respondents rate their agreement (1, total disagreement; 9, total agreement) on each sentence of the items. These sentence scores are scaled into quantitative indices (-1, +1), whose meaning is invariant across all sentences: the higher (lower) the index score, the higher (lower) the belief’s correctness according to the current knowledge from history, philosophy and sociology of S&T (Vázquez & Manassero, 1999; Vázquez et al. 2006). Averaging the sentence indices within each item, four new indices are produced: three indices for the three groups of sentences (categories) and one global index for the whole item. Thus, this scheme describes the teacher’s through on NoS through over one hundred and fifty invariant indices (sentence, category and item indices). The index scores allow the use of inferential statistics for hypothesis testing, which can be applied to compare groups (pre-service vs. in-service teachers), or to set up cutting points for identifying the strengths (highest positive), weaknesses (lowest negative), and neutral beliefs (Vázquez, Manassero & Acevedo, 2006). The criteria to achieve relevance are the statistical significance ($p < .001$), and the effect size of the differences (differences measured in standard deviation units; $d > .30$).

RESULTS

The diagnostic methodology evaluates each item through a set of variables that includes the sentence indices, the three category average indices, and the overall item index (average of the three categories). The grand mean of the item indices for all teacher sample are slightly different for the form 1 ($m = .1862; DE = .5456$) and for the form 2 ($m = .0809; DE = .5531$); both are positive, but quite close to the null value. This result can be interpreted as a
indicating neutral though somewhat positive conceptions towards NoS issues; some positive indices compensate the negative ones to produce this approximately neutral value for the global mean of the entire sample, which suggests that informed beliefs coexist with other less informed beliefs.

**Teachers’ strengths and weaknesses**

The distribution of the average item indices is displayed in figure 1 and 2 for both forms (F1 and F2). Both figures show asymmetrical distributions, where most of items are placed in the positive area (F1 that has only one item in the negative area of item index scores.

![Figure 1. Average item indices for the 15 questions of the Form 1.](image)

The items with the highest positive indices (more than one standard deviation above zero) identify the teachers’ strengths and weaknesses. The list of F1 and F2 items, which represent a teachers’ strength, is the following: F1_30111 STS Interaction, F1_40161 Social Responsibility contamination, F1_20141 Government politics a country, F1_10111 Science F2_10421 Interdependence Quality of life, F2_50111 Union two cultures, and F2_60521 Gender equity.

Some items reach negative scores in both forms (F1 and F2), though their mean indices do not attain low enough scores to be considered symmetrical to the positive ones. Nonetheless, the items with negative indices, which represent a teachers’ weakness, are the following: F1_20411 Ethics, F2_40421 Application to daily life, F2_90111 Observations.

![Figure 2. Average item indices for the 15 questions of the Form 2.](image)

Similarly, the categorical and the sentence variables with highest positive and lowest negative indices could be used to identify the specific strengths and weaknesses. Each of the hundred sentences represents a specific conception on NoS, and the whole set conform the teacher’s thinking; approximately, two third of them do not attain a satisfactory level to be deemed quality conceptions for a fair science teacher. The number of these variables that are high and low is still greater than previous ones to be displayed here in the affordable space of this paper. The following example displays the classification of the sentences in an item as weakness, strengths, or medium, according to their mean index scores.
Table 2. Text of an item (10421) that displays the classification of its sentences as weaknesses (italic), strengths (bold), and medium, according to their mean index scores.

<table>
<thead>
<tr>
<th>10421</th>
<th>In order to improve the quality of living in our country, it would be better to spend money on technological research RATHER THAN scientific research.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Invest in technological research because it will improve production, economic growth, and unemployment. These are far more important than anything that scientific research has to offer.</strong></td>
<td></td>
</tr>
<tr>
<td>Invest in both:</td>
<td></td>
</tr>
<tr>
<td><strong>B. because there is really no difference between science and technology.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>C. because scientific knowledge is needed to make technological advances.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>D. because they interact and complement each other equally. Technology gives as much to science as science gives to technology.</strong></td>
<td></td>
</tr>
<tr>
<td>E. because each in its own way brings advantages to society. For example, science brings medical and environmental advances, while technology brings improved conveniences and efficiency.</td>
<td></td>
</tr>
<tr>
<td><strong>F. Invest in scientific research – that is, medical or environmental research – because these are more important than making better appliances, computers, or other products of technological research.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>G. Invest in scientific research because it improves the quality of life (for example, medical cures, answers to pollution, and increased knowledge). Technological research, on the other hand, has worsened the quality of life (for example, atomic bombs, pollution, automation, etc.).</strong></td>
<td></td>
</tr>
<tr>
<td><strong>H. Invest in neither. The quality of living will not improve with advances in science and technology, but will improve with investments in other sectors of society (for example, social welfare, education, job creation programs, the fine arts, foreign aid, etc.).</strong></td>
<td></td>
</tr>
</tbody>
</table>

The previous table evidences some common features for all items: on each issue (item), the teachers hold at the same time strengths and weaknesses. Some sentences exhibit appropriate conceptions (A, D, G, H), while the remaining sentences feature uninformed conceptions, either a clear weakness (C) or a conceptions that not attain a sufficient high level to meet the teachers needs for a quality teaching of NoS (B, E, F).

**Differences between pre-service and in-service teachers**

The methodology allows the application of inferential statistics in hypothesis testing, in particular, the simplest form of testing refers to group comparison, which is applied here to compare NoS conceptions of pre-service and in-service teachers. To find out the variables that might display significant differences between groups, a two-way between-groups analysis of variance was conducted to explore the impact of teaching practice on teachers’ NoS understanding, as measured by the three hundred variables of questions, categories and sentences (dependent variables).

Overall, few variables (19 for the form 1, and 24 for the form 2 of the total 300 variables involved in the two forms) displayed a statistically significant main effect (p < .01; d > .30) between in-service and pre-service teachers. However, the differences do not display the same sign, as some differences are positive (in-service teachers score higher than pre-service teachers), and other are negatives (in-service teachers score lower than pre-service teachers). Thus, not only the relevant differences are comparatively scarce, but also they do not display the same trend for all the significant variables favouring one group over the other.

Summing up, these results do not support the hypothesis that the practice of science teaching improves teachers NoS conceptions. This is evidence that improving NoS understanding requires explicit teaching of NoS contents, and implicit practices such as teaching science are not enough to improve teachers’ conceptions.
CONCLUSIONS AND IMPLICATIONS

The new instrument and methodology improves the validity and reliability of the previous instruments and avoids the usual objections, such as forced answer (election of just one sentence). Moreover, they contribute to identify qualitative features, such as strengthens and weaknesses of NoS understanding, and to normalize the scores and analyses, which allows standardized application of the hypothesis testing statistics, such as comparisons among groups. On the other hand, the methodology allows quick and easy assessments for big representative samples, which overcomes the limitations to case studies or small samples, to identify the teachers’ strongest beliefs (those that highly fit the experts’ current knowledge), and the teachers’ weakest beliefs (those that oppose the experts’ knowledge).

The assessment instrument and method fit the requirements suggested by Allchin (2011) for appropriately assessing functional NoS understanding: authentic context, well-informed analysis, adaptability to diagnostic, formative or summative evaluation, adaptability to single, mass, local or large-scale comparative use and the respect for relevant stakeholders; further, the research project PIEARCTS is an example of large-scale applications across seven countries and involving over 16,000 valid answers (Bennássar-Roig, Vázquez-Alonso, Manassero-Mas, García-Carmona, 2010; Manassero et al., 2010).

The results provide a picture of teachers’ NoS conceptions more complex than usual (Lederman, 2007): the teachers’ poor conceptions coexist with the appropriate ones across all the NoS topics. Many teachers’ NoS conceptions (about two third of explored conceptions) do not achieve the high level required to quality teaching of NoS. The appropriate beliefs could be educationally worth, because they can be used as pedagogical hooks in teacher training and the planning of teaching NoS curriculum.

It is usually agreed that years of teaching improves the teachers’ pedagogical content knowledge, so that in-service teachers would have displayed higher scores than pre-service teachers (Abd-El-Khalick & Lederman, 2000; Lederman, 2007). In spite of this somewhat optimistic trait, the comparisons between pre-service and in-service teachers display scarce relevant differences: the differences in favour of pre-service teachers balance those in favour of in-service teachers, and both groups seem more similar than different. As Spanish teachers have not been taught on NoS (control variable), this study evidences that science teaching practice by itself does not contribute to refine the teachers’ NoS conceptions. Thus, it would not be expected that teaching experience could (implicitly) train teachers on NoS. This claim agrees with the current compelling evidence in favour of explicit teaching of NoS.

All in all, the numerous inappropriate, or simply insufficiently appropriate conceptions found in the science teachers' thinking, together with the lack of effectiveness of teaching experience to improve this situation, put forward the necessity of designing and implementing training programs that involve teachers in an explicit and reflexive analysis of NoS topics for both pre- and in-service teacher education (Hanuscín, Akerson & Phillipson-Mower, 2006). The aim ought not to be teachercs become philosophers of science, or better knowledgeable on NoS, but more competent teachers to teach effectively NoS issues within science classroom.

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DEVELOPING CHILDREN’S VIEWS OF THE NATURE OF SCIENCE THROUGH ROLE PLAY

Cakici, YILMAZ and BAYIR, Eylem
Trakya University, Turkey

Abstract: In this study, we aimed to investigate the effect of using role play (portraying a scientist”s life story) on the children”s views of the nature of science (NOS). The study was carried out at the Children”s University of Trakya in Turkey in 2010. The research sample consisted of 18 children, aged 10 to 11. Children met for ten days for approximately three hours per day. They completed the pre- and post-tests including 16 open-ended questions in order to reveal changes in their views of the NOS before and after the role play activities. The findings revealed that the children had more informed views of the target NOS aspects in comparison to their views prior to the role play activities. A large majority of the children (around 80-85 percent) started out with naive conceptions of the target NOS aspects. Following the role play activities portraying scientists” lives, there was a 40-45 percent positive change in children”s views of the tentative, empirical and creative/imaginative aspect of the NOS. The most substantial change occurred in their views concerning scientific method, with a shift of 72 percent. These results indicate that role play oriented activities portraying scientist”s life stories could be used as one of the exciting and constructive ways of developing children”s understanding of the NOS.

Keywords: Nature of science, role play, drama, primary science.

INTRODUCTION

In the last two decades, the nature of science, as an essential component of scientific literacy, has become a slogan in science education all over the world. Many reform documents in science education (AAAS, 1993; NRC, 1996) emphasized the crucial role of enhancing students” informed views of aspects of the NOS. AAAS (1993) and NRC (1996) underlined that scientific fact/knowledge oriented science teaching focusing narrowly on the laws, concepts, and theories of science does not lead to an understanding of how science itself works. In order to overcome this deficiency, the strong focus for pupils in the early grades, should be on gaining experience with natural and social phenomena, and on enjoying science. Compared to traditional methods of science teaching, use of role play/drama to portray the lives of scientists may provide students with “a more authentic sense of science”, especially regarding how science works (Boujaoude et al., 2005, p.259). Odegaard (2003), in her extensive review of the literature on drama activities in science education, emphasized that the use of drama in a well-considered manner with the guidance of reflective science teachers may offer creative and non-authoritarian learning environments for students. Through stories of science and the experience of enacting scientists” lives, students may gain better insight into the nature of scientific practice. According to Yoon (2006), two characteristics of science drama are worth of emphasis; 'story' and 'liveliness' of its performance. While events and characters in the “story” enable individual emotional participation and empathetic learning, the „liveliness” of science drama allows students to express and adapt their ideas in a learning environment which is quite non-authoritative.
Despite the successful performance of 'The Blegdamsvej Faust' drama in 1932 by Bohr's students, there is still a dearth of studies on role play/drama in science education. However, the few studies reported in the literature found that role play/drama has a positive effect on children’s science learning. Bailey and Watson (1998) investigated the advantages of utilizing drama/role play in developing understanding of basic ecological concepts with students aged 7 to 11. They reported that a structured role play activity, the Eco game, as an active learning strategy appeared to have an important part to play in the generation of concepts relating to ecology. Boujaoude et al. (2005) explored the effect on conceptions of the NOS of using drama as a supporting learning strategy with older students from grade 10 and 11. At the end of the study, it was found that the students who participated in the drama activities possessed more informed the NOS views than the control group.

RATIONALE

In this study, we aim to investigate the effect of using role play activity portraying a scientist’s life story on upper primary level children”s views of the NOS. We focus on the tentative, empirical, denial of a prescribed scientific method and on the creative/imaginative NOS. By critically investigating scientists” lives and work methods and by role playing, students might become aware that scientists fail as much as they accomplish (Boujaoude et al., 2005, p.259), that they do not follow a universally accepted a scientific method, that science does not provide absolute proof, and finally students may substitute their naive NOS views with informed ones.

METHODS

The study was carried out at the Children’s University of Trakya in the Northwest part of Turkey and was organized during the summer of 2010. The participants consisted of 18 children, aged 10 to 11. The study lasted two weeks (ten week days) and approximately three hours per day including breaks. The pre- and post-tests including 16 open-ended questions were used.

In this study, the life story of two scientists (Isaac Newton and Marie Curie) was selected for the role play activities to be performed by the children. The authors initially prepared a power point presentation about the lives of those scientists. Both researchers simultaneously supervised the participants during the role play activities. On the first day, after a brief introduction, the pre- test was given to the children. Then, in order to attract the children”s attention to the lives of the scientists, the researchers directed various questions concerning the scientists. During this activity, students were all given the opportunity to express their ideas freely about the scientists and scientific process. This was followed with the presentation of the lives of two scientists.

On the second day, the children were divided into three groups of 6. While one group of children performed the role play, the others participated as the audience but the groups all had a chance to role play at least once. Performers initially were selected as volunteer among the children. Then, the researchers introduced a detailed step by step description of the life of Newton. At intervals during the presentation, the researchers portrayed the roles which children would be invited to play, and encouraged the children to focus on, talk and improvise about critical incidences in the scientist’s life. Later, the authors, together with children”s help, prepared the classroom so that the children could characterize some crucial instances in Newton’s life. On the third day, the children performed the role play. The children were reminded by the authors what role they would play and given a brief outline of the situation to be portrayed. At each stage, children were encouraged to improvise within the situation to be portrayed.
On the fourth day, the children were experienced in role play, and thus performed their roles more successfully in a relaxed and pleasant atmosphere. Some students were really very eager to repeat the role play. Hence authors required the children to take turn in different roles as they performed with their classmates. During the role play activity, we explicitly asked a number of critical/taught provoking questions in order to touch aspects of NOS. “What do you think of how Newton showed the existence of gravity?” “Where is the gravity in this class?” In this way, children had an opportunity to think about the NOS. Fifth day started out with a small ice-cream party, aiming to encourage children to chat more enthusiastically and answer questions about the NOS e.g. “Do you think that Newton and previous scientists think same thing? Why?” The following week, a similar strategy was adopted illustrating the life of Marie Curie.

RESULTS

Student responses were categorized as naive and informed. Naive category represented inadequate responses with regard to the target NOS aspect. For example, some students stated that scientific knowledge was subject to change over time but attributed that change solely to the development of new technologies or the accumulation of new data. Informed category included responses referring reinterpretation of existing data from a different perspective. Student responses were initially categorised independently by two of the researchers. The researchers sorted out differences by reviewing the responses. Here, we report the children’s responses to four questions in the pre and post-test. The question “Do you think that all scientific knowledge in your science books can change over time? Please, explain your reason” assessed students’ understanding of the tentative NOS. Although only 3 children (17%) in the pre-test provided informed views about the tentativeness of science, this increased to 11 (61%) after role play activity. While one child in the pre-test determined change to be solely due to technological developments, in the post-test she stated that “different scientists may think differently and produce new things like atom models. Newton’s ideas were different from the previous scientist.” The question targeted the empirical nature of science asked children “For you, how science is different from the other subjects you are studying?” While 39 percent of the children gave relatively informed statements, this increased to 78 percent in the post-test. The following is a child’s statements in the pre and post-test respectively: “Science explains to us everything in the world. Through the experiments, science provides absolute knowledge.” “Science saves us from wrong knowledge. For science, investigating nature and space, and making experiments are very important.”

The question about multiple methods of investigation revealed the most substantial shift in the views of children. Although none of the children initially held informed views of scientific method, following engagement with the role play activities informed views rose to 72 percent. For example, a child initially stated that “scientific method is very important. To be successful and practical, a scientist should simply follow scientific method and pursue the way of doing science as the previous scientist”. However, after the role play, the same child stated that “I think deep thinking and questioning about things, like Newton, to be a better way of doing science. We do not need to memorize scientific method.” When asked about the role of human creativity and imagination in science, informed views increased from 22 percent to 67 percent after role play. One child expressed that “Without imagination, scientist cannot put forth big things. Deep thinking and imagination help scientist to find out new things.”
CONCLUSIONS AND IMPLICATIONS

Role playing scientists’ life stories through the guidance of the reflective authors and explicit instruction appeared to have helped children’s understanding of how science/scientist works, and finally develop a sense of the target NOS aspects. Although a great majority of children (around 80-85%) started out with naive conceptions of the NOS, following the role play activities portraying scientists’ lives, they tended to develop more informed views of the target NOS aspects. The positive changes were observed for all of the NOS aspects with the most substantial change occurring with the questioning of universally accepted scientific method showing a shift from zero to 72 percent. The shift for the tentative, empirical and creative and imaginative NOS stayed about 40-45 percent. These results support using role play/drama activities to bring about positive changes in students’ NOS views as previously stated by Boujaoude et al. (2005). It should be noted that in spite of the fact that role play activities improved the children’s NOS views, just a two week intervention at the children’s university may not be enough for assimilation and retention the meanings of the NOS aspects.

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