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Research in Biological Education

Research in Biological Education

A selection of papers presented at the IX[th] Conference of European Researchers in Didactics of Biology (ERIDOB)

Edited by
Dirk Krüger
Margareta Ekborg

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TABLE OF CONTENTS

PREFACE

This volume contains 14 selected papers from the 9th Conference of European Researchers in Didactics of Biology (ERIDOB). ERIDOB's well established conferences attract about 200 biology education researchers from Europe as well as from counties far beyond its borders. For 16 years now, researchers in didactics of biology have come together at the biennial conference to exchange research questions, designs, instruments, results, interpretations, and conclusions. The intention of ERIDOB is to provide an opportunity for researchers with diverse experiences to discuss biology education research.

In order to widen the field of themes for discussion and submission of interesting papers from researchers of biology didactics, the academic committee at the last ERIDOB conference in Braga, Portugal, 2008 decided not to select a theme for the 2012 conference. The 2012 conference was organized by and held at Freie Universität Berlin, in Berlin, Germany. From initially over 170 contributions, 56 papers were presented as oral presentations and 58 as poster presentations at the 9th conference. All presentations were arranged in 12 strands: Environmental education; health education; biology education in informal settings; scientific thinking; argumentation; models and modeling; teaching strategies; teaching socio-scientific issues; teaching genetics; pedagogical content knowledge; student conceptions; interest and motivation; and two symposia: supporting students' interactions with socio-scientific issues; teaching evolution: cognitive and affective factors.

All papers presented at the conference and published have been double reviewed by a minimum of one member of the academic committee and by one experienced participant of ERIDOB and reviewer of biology educational journals. Out of twenty excellent papers chosen for publication in the proceedings of the ERIDOB conference six were included in a special issue of the Journal of Biological Education (Vol. 47, Issue 3, 2013). The choice of papers was based on the intention to illustrate both the high quality and diversity of current European research in biological education. The 14 papers presented in this volume address topics in the areas of student conceptions, teacher conceptions and teacher knowledge (section 1), biology education in informal settings (section 2), models and modeling (section 3), and teaching strategies, teaching socio-scientific issues and curriculum development (section 4).

The next ERIDOB conference takes place at the University of Haifa, Israel, in 2014. The family atmosphere of an ERIDOB conference offers possibilities of recognising and exploring European research cultures with the intention of building a strong and internationally coherent research culture. Newcomers are warmly welcomed.

D. Krüger Margareta Ekborg

Dirk Krüger Margareta Ekborg

SECTION 1

Student conceptions, teacher conceptions and teacher knowledge

1 THE ROLE OF CONCEPTIONS, METAPHORS, AND ANALOGIES IN STUDENTS' UNDERSTANDING OF SEEING

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Abstract

For more than 30 years, students' conceptions have been perceived as an important factor to describe how students understand scientific phenomena. To understand abstract phenomena, metaphors and analogies are seen as fundamental by the theory of experientialism. The aims of this study are to investigate 1) whether explicit mentioning of students' individual conceptions, metaphors, and analogies is fostering understanding of vision and perception, 2) the extent to which metaphors and analogies are helpful, and 3) How different ways of understanding influence the success and retention of conceptual reconstruction.

Three groups of students (N = 217) were compared: individual conceptions were considered and reflected upon in the first group, while the second group learned with the same materials irrespective of their individual conceptions, and the control group had no instruction concerning vision at all. Students' everyday and scientific conceptions were tested before and after the instruction and three months later. The metaphors and analogies students drew, commented, or reflected using worksheets were analyzed by qualitative content analysis.

In most cases the results of the students were significantly better if their individual conceptions were considered and reflected upon. Notably in this study, abstract conceptions were only reconstructed if the individual conceptions were explicitly mentioned. The interpretation of students' metaphors and analogies shows that they can be the key to successful reconstruction of abstract conceptions, if explicitly reflected upon.

1. Introduction

Over the last 30 years the role of individual conceptions in understanding has been intensely discussed in biology education (Duit, 1995; Kattmann, 2007). Metaphors and analogies have been mentioned as a basis for conceptual understanding of abstract phenomena (Lakoff & Johnson, 1997; Gentner et al., 1997). Therefore, metaphors and analogies are not just seen as linguistic or rhetoric phenomena but as fundamental for thinking (Lakoff & Johnson, 1997; Schmitt, 2005).

In this study, the biological topic of vision and perception is chosen to examine conceptions, metaphors, and analogies that may empower students to reach better scientific understanding. Some implications for the design of learning environments considering metaphors and analogies are discussed. The topic of vision allows us to examine a broad spectrum of conceptions that are differently understood due to their sources:

- physical conceptions that are based on direct experience, e.g. the *role of light*
- abstract conceptions of phenomena that cannot be experienced and have to be understood imaginatively by using metaphors or analogies, e.g. the *relation between object and eye* or the conception of an *image* that is generated in the process of seeing
- abstract and epistemological conceptions which have also to be understood imaginatively, but in addition have epistemological significance, e.g. the so called *everyday realism* (Gropengießer, 2001) – the conception that we are able to see the world as it really is – in contrast to constructivist ideas

This study focuses on three research questions:

1. To what extent does instruction that explicitly considers individual students' conceptions, metaphors, and analogies support conceptual reconstruction?
2. Which metaphors and analogies foster or hinder students' understanding of the process of seeing?
3. How do different ways to gain understanding – by direct experience or imaginative mapping – influence the success and retention of conceptual reconstruction?

To investigate these questions different learning environments were designed that either allow direct experiences or use typical metaphors and analogies and ask students to reflect on their conceptual use.

2. Theoretical background

2.1 Constructivist perspective on learning

In this study, thinking and learning are understood from a constructivist perspective, i.e. conceptions are constructed based on perceptions. These conceptions are tested in everyday situations and if they are viable they are affirmed. Learning environments should enable students to scrutinize their conceptions and possibly (re)construct them situationally, actively, and self-directedly (Duit, 1995; Reinmann & Mandl, 2006; Riemeier, 2007). These basic conditions have to be considered for the design of learning environments.

2.2 The theory of experientialism – A theory of understanding

The theory of experientialism explains how understanding takes place. It describes the sources of understanding. The main point is that understanding is experience-based. In some cases, direct understanding is possible because we can make experiences. Concerning the process of seeing, students experience that they only see objects in a room if there is light. The conceptions that are generated by those direct experiences are called embodied schemata. In contrast, abstract phenomena that cannot be experienced have to be understood imaginatively: the embodied schemata are used as sources that are mapped on the abstract phenomenon in order to explain it. Doing this they are used as metaphors or analogies. What happens between the eyes and the object cannot be experienced in the process of seeing, so students have to use metaphorical or analogical mapping to understand this process (Figure 1).

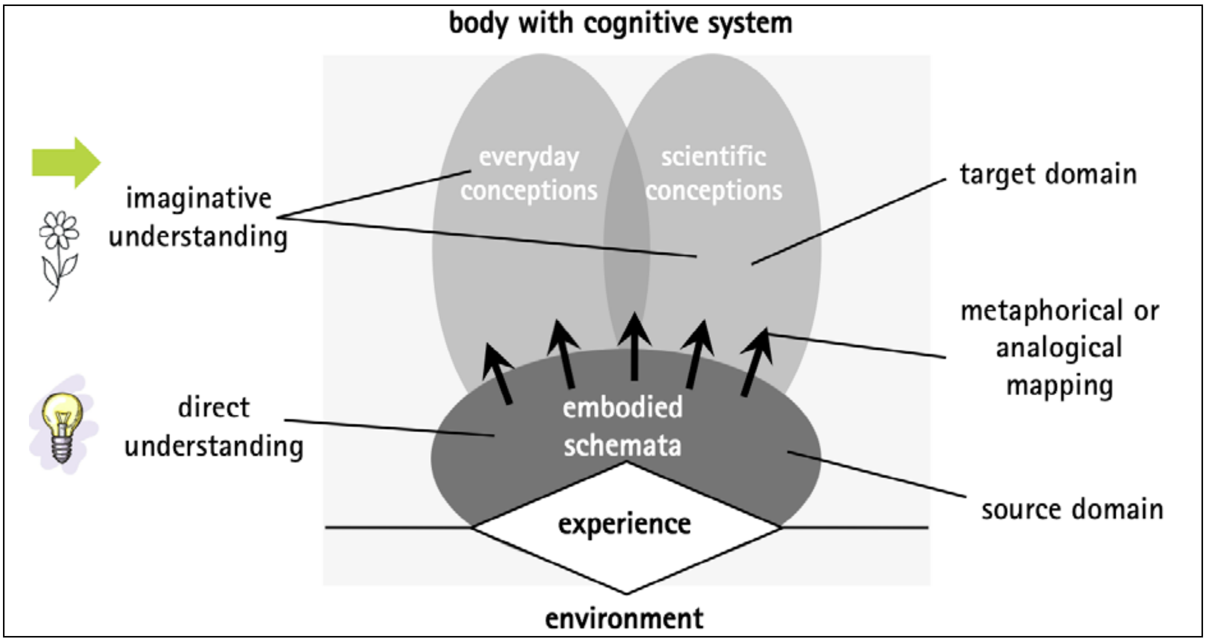

Figure 1. The theory of experientialism (based on Gropengießer, 2007, p. 112; the bulb symbolizes the *role of light*; the arrow symbolizes the *relation between object and eye* and the flower the conception of an *image*).

One common metaphorical schema used by students to explain this process is the start-path-goal schema (Figure 2). It is even used among university students' science textbooks (Campbell et al., 2003, p. 1276). This schema emerges from the experience that we start at one point to get somewhere, cover a distance, and then finally reach our goal (Lakoff & Johnson, 1990, 1997). Another example of abstract phenomena that make imaginative understanding necessary is the question of what is transferred into our eye or brain. Many students hold the conception that an *image* of the object arises in the eye (on the retina) or/and in the brain (Figure 3). Here another basic experience is used as a source domain: seeing oneself or another object in a mirror.

Lakoff and Johnson (1997) do not differentiate between metaphor and analogy. In this study, however, a distinction is necessary. The metaphorical mapping of a source domain on a target domain is happening unconsciously. Metaphors can be reflected and then become an object of metacognition. In contrast, the term "analogy" is used to mark that the mapping process is reflected upon, and we consciously use a specific source domain or specific terms to explain a target domain.

Some conceptions have epistemological character and are therefore affecting other conceptions. They provide a basic framework for these other conceptions so that conceptions that do not fit in this frame are unconsciously excluded. Therefore, the framework affects the conceptual understanding of a domain (Lakoff & Johnson, 1997). One example concerning the process of seeing is the conception of *everyday realism*: we perceive the world as it really is. In many cases this conception correlates with the metaphor of an *image* of the flower that is generated in the process of seeing. According to a constructivist perspective this conception is not seen as a scientific one.

2.3 Conceptual reconstruction

A way to reconstruct conceptions from everyday to scientific conceptions is described by the theoretical framework of conceptual change (Posner et al., 1982; Strike & Posner, 1992). The term "everyday conceptions" describes conceptions which are constructed in everyday situations and which are mostly not corresponding to scientific ones. The reconstruction of metaphors and the reflective use of analogies are perceived according to conceptual change as well. Strike and Posner (1992) describe four phases that enable students to reconstruct their conceptions: students have to be dissatisfied with the explanatory power of their recent everyday conception and the scientific conception has to be understandable, plausible, and fruitful. This constructive process is not seen as a total and rapid change from an everyday to the scientific conception. To mark this the term conceptual reconstruction (Duit, 1999) is used and the possibility to choose between everyday and scientific conceptions in different situations is mentioned as its aim. In this study we analyzed the qualitative and quantitative differences between the use of everyday and scientific conceptions in the pre-, the post-, and the follow up-test to rate the students' learning success.

Several studies have shown that students hardly reconstruct their conceptions, especially their everyday conceptions even after scientific-oriented interventions (Chinn & Brewer, 1993; Duit & Treagust, 1998; Treagust & Duit, 2008). A meta-analysis of different conceptual change-strategies has shown that explicitly contrasting students' everyday conceptions with the scientific ones can have positive effects (Guzetti & Glass, 1992). Metacognitive awareness of conceptions is also seen as beneficial for conceptual reconstruction and its sustainability because students reflect on their recent everyday conceptions and their learning process (Gunstone & Mitchell, 1997). Vosniadou (2002) differentiates between imaginatively generated conceptions and epistemological framing conceptions. Both are generated for abstract phenomena but epistemological conceptions, e.g. the *everyday realism* that was mentioned before, influence the whole basic understanding of a topic. They provide a framework for the other conceptions and can affect their understanding. Therefore, they are fundamental and even more difficult to reconstruct in learning processes.

The learning environments used in this study were designed according to these requirements.

3. Research questions

The study focuses on the following research questions:

- To what extent does instruction that explicitly considers individual students' conceptions, metaphors, and analogies support conceptual reconstruction?
- Which metaphors and analogies foster or hinder students' understanding of the process of seeing?
- How do different ways to gain understanding – by direct experience or imaginative mapping – influence the success and retention of conceptual reconstruction?

4. Research design and methods

To examine these research questions three different groups (*N* = 217, grades 8 and 9 (13 to 15 year old)) were compared in a pre-post-follow up-test-design. The intervention lasted two weeks and the treatment was different in all groups:

- Intervention group I: the students (n = 73) got material adapted to their individual conceptions, prominent metaphors, and analogies were explicitly reflected upon
- Intervention group II: the same material was used irrespective of students' (n = 71) individual conceptions, metaphors, and analogies
- Control group: the control group (n = 73) had no instruction concerning vision. In biology classes the control group was dealing with other topics like photosynthesis or the immune system.

To determine students' conceptions of seeing and perception, computer software was used (Dannemann & Krüger, 2010). The software measures the qualitative (Which conception is chosen in which situation?) and quantitative (How often is a conception used in different situations?) differences between the use of everyday and scientific conceptions to rate the students' learning success. To examine the second and the third research question, the conceptions of all students were tested before and after the treatment and in a follow up-test three months later to test the sustainability of the conceptual reconstructions. The control group B did not perform the follow up-test due to curricular demands. They learned about the topic of vision in the meantime. The results of the pre-, the post-, and the follow up-test were statistically compared using tests for non-parametrical data (Kruskal-Wallis, Wilcoxon).

Students' metaphors and analogies were analyzed using their drawings and comments on worksheets in the different learning environments. Qualitative content analysis (Gropengießer, 2005; Mayring, 2007) was used to interpret them.

4.1 Design of the learning environments

The process of designing the learning environments was based on the model of educational reconstruction (Kattmann, 2007). Everyday and scientific conceptions were compared and the results were used to design them. To figure out prominent and frequent everyday conceptions, studies about students' conceptions of the process of seeing were reanalyzed (e.g. Andersson & Kärrqvist, 1983; Gropengießer, 2001; Guesne, 1985; Wiesner, 1995). To complement the results a pilot study with five classes (N = 142) was conducted and prominent and frequent conceptions, metaphors and analogies were identified. The learning materials were designed according to the requirements of experimentalism and conceptual change mentioned above.

4.2 Prominent students' conceptions, metaphors, and analogies of seeing

The following sketches were drawn at the pretest of this study. They are used as examples to show prominent conceptions, metaphors and analogies. Similar sketches to draw on were used in several studies before (Andersson & Kärrqvist, 1983; Gropengießer, 2001). The students were asked to complete the sketch so that it explains their idea of the process of seeing.

Before the intervention student DR (initials of the students) drew arrows that point at the flower and also in the other direction (Figure 2). In the text below, he explains: "The eye emits seeing rays which are reflected back into the eye. That is how we see." This everyday conception is called *reflection*. DR uses a common metaphor, the start-path-goal schema twice in contrasting directions (Figure 2, green lines): first it is directed from the eye to the flower and represents a "seeing ray". These "seeing rays" "touch" or "hit" the flower and then are reflected back into the eye. To show that something is led to the brain DR uses the start-path-goal schema a third time.

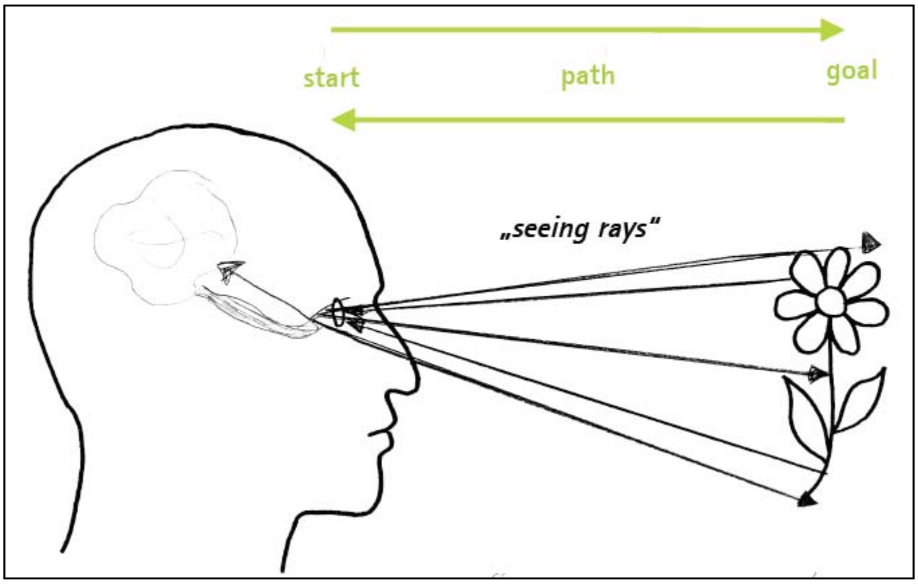

Figure 2. DR's drawing (black lines) before the intervention (pretest) as an example for students' conceptions of the *relation between object and eye.*

The second drawing (Figure 3) shows an *image* of the flower that is generated in the eye and turned around in the brain. In the pretest, 92 % of the students held the conception that an *image* of the original object is generated in the process of seeing. Most of them also think that this *image* is an exact copy of the object that is perceived and also have the epistemological conception of *everyday realism* as a conceptual framework. According to student RA the only function of the brain – that is not drawn but written down in the sketch of the head – is to turn the *image* around after it was reversed in the eye.

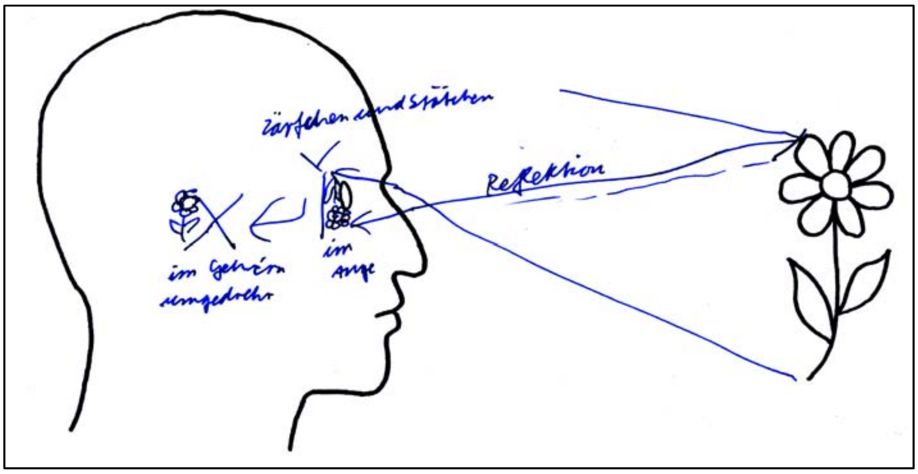

Figure 3. RA's drawing before the intervention (pretest) as an example for students' conception of an *image* that is generated in the process of seeing (text written down in the drawing from the right to the left side: reflection, cones and rod receptors, in the eye, turned around in the brain).

Figure 4 shows an example of a science-oriented conception. Student BC has additionally drawn light which was missing in the other examples. In the pretest, 63 % of the students do not have the reliable conception that light is necessary for seeing. To explain the *relations between object and eye* BC also uses the start-path-goal schema. And this metaphor is also helpful to describe the relations between the light source and the object. But in contrast to DR's drawing, the arrows in BC's drawing represent the light that is directed to the flower and is reflected into the eye. So he just draws the arrows in one direction. This gives clues that the conception of what is represented by the arrows is a key to a scientific understanding. BC has not drawn an *image* of the flower that is generated in the eye or the brain. In his opinion, information is sent to the brain.

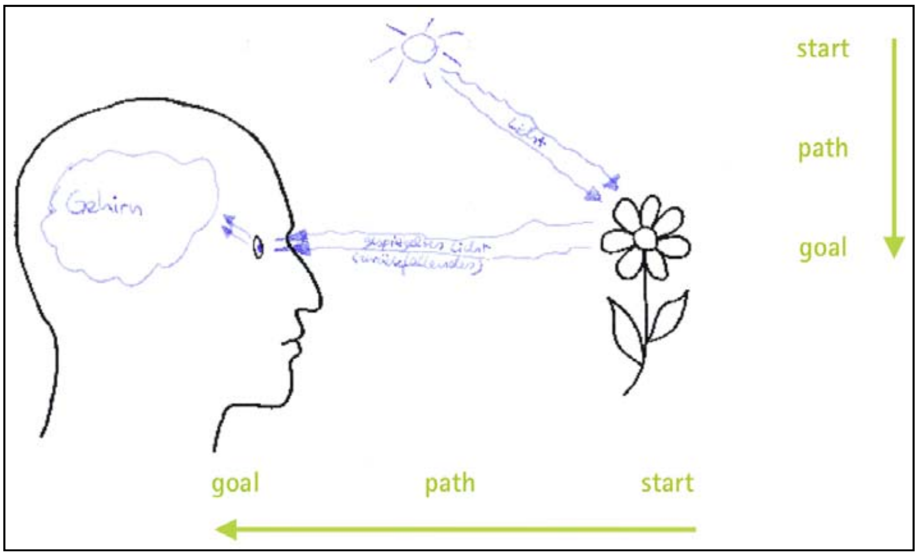

Figure 4. BC's drawing before the intervention (pretest) as an example for science-oriented conceptions of *light*, *relations between object and eye* and *image* (text written down in the drawing from the right to the left side: light, reflected and mirrored light, brain).

The results of the analysis of students' drawings and comments were used to design the learning environments for the intervention study.

4.3 Guidelines for the design of the learning environments

The theory of experientialism describes two different ways to gain understanding: providing direct experience and the reflection on conceptions. Some conceptions of seeing are experience-based, e.g. the *role of light*: To enable students to (re)construct their conception of this topic they are offered experiences with light. Therefore, we use a box with a back wall that is slowly opened while the student looks into the box. Consequently, he can experience that he sees nothing inside the box as long as there is no light. Based on this experience the student is given a possibility to reconstruct his conception concerning the *role of light*.

The interventions that deal with imaginative understanding are using prominent metaphors or analogies that are explicitly described and contrasted with the scientific conceptions. Students and scientific textbooks use the start-path-goal schema to explain what happens between the object and the eye in the process of seeing (cf. Figure 2 and Figure 4). Thus, the start-path-goal schema can be seen as a helpful metaphor to understand this part of the process of seeing. Student DR, for example, can retain his start-path-goal schema because even scientists use it to understand the scientific conception. But he has to invert the direction and to reconstruct his idea of the seeing rays that are emitted by the eye. Here the experience that light is necessary to see is helpful. It seems to be the missing link for explaining the processes between the object and the eye.

Understanding this process lacks direct experience. Therefore, we designed working sheets in a specific way: prominent metaphors of extrospection and reflection like "seeing rays", a "sonar", or "rays that measure out the object" are contrasted with the scientific concept that light is reflected from the object into the eye. The students can reflect on their individual conception. Sketches support this way of learning. They use the start-path-goal schema and contrast the representation of the everyday conception with the scientific one.

The learning environment for reconstructing the conception that an *image* is generated in the process of seeing reflects on a prominent analogy: the eye works like a camera and seeing is like taking a photo. Many students use this analogy because it is often described in physics or biology textbooks in order to foster students' understanding of the optical parts of the process of seeing.

To support metacognitive awareness and reflection the working sheets were structured in a specific way: at first the students have to phrase and/or draw their recent conception. Immediately after that they get in touch with the scientific conception which is explicitly contrasted with the everyday conception. Finally, they have to write down again their recent understanding and compare it with their statement before.

To answer the second research question the start-path-goal schema seems to be a very helpful metaphor to understand the processes between object and eye. In contrast, the analogies of the eye as a camera and an *image* that arises in the eye are hindering a scientific understanding. Therefore, we explicitly reflected on them in the learning environments.

5. Findings and discussion

5.1 The role of individual conceptions, metaphors and analogies in students' understanding of seeing

To examine whether the consideration of students' individual conceptions and metaphors helps to reconstruct their everyday conceptions, we tested their performance before and after the intervention. To analyze the sustainability of the treatment they were also tested three months later. The results of the three measurement dates were compared. The testing before the instruction showed no significant difference between the three groups (Kruskal-Wallis-test: pretest: .260 (n.s.)).

The results are presented for the three aspects: *role of light* (direct experience), *relations between object and eye* (imaginative understanding) and the *image* that is generated in the process of seeing (imaginative understanding in the epistemological framework of *everyday realism*). Therefore, the results also give clues to respond to the third research question.

5.2 The *role of light* – Direct experience

Concerning the *role of light* significant differences could be shown in both intervention groups from pre- to posttest.

Table 1. The *role of light* – Comparison of the results of the pre- and posttest, and the follow up-test (Wilcoxon)

	Pre-Post-Test	Pre-Follow up-Test	Post-Follow up-Test
Intervention group I	$p < .001$ $r = .61$	$p < .001$ $r = .44$	p = n.s. $r = .21$
Intervention group II	$p < .001$ $r = .43$	$p < .05$ $r = .28$	p = n.s. $r = .11$
Control group	p = n.s. $r = .05$		

The effect in intervention group I is even larger than in intervention group II – more students have reconstructed their conceptions (intervention group I: 44%; intervention group II: 21%). The results of the follow up-test show that the students of the intervention group I retained the scientific conception better. Between the post- and the follow up-test no significant differences were found. As expected, no significant differences were also found in the control group between the pre- and the post-test. So if direct experience is possible students profit even if their individual conceptions are not explicitly mentioned. But if individual conceptions are considered more students are reconstructing them and retain them longer.

5.3 The *relations between object and eye* – Imaginative understanding by using the start-path-goal schema

The results show that only students from intervention group I reconstructed their everyday conceptions. They were even able to use the scientific conception in the follow up-test.

Table 2. The *relations between object and eye* – Comparison of the results of the pre- and posttest, and the follow up-test (Wilcoxon)

	Pre-Post-Test	Pre-Follow up-Test	Post-Follow up-Test
Intervention group I	$p < .001$ $r = .41$	$p < .05$ $r = .32$	p = n.s. $r = .17$
Intervention group II	p = n.s. $r = .11$	p = n.s. $r = .06$	p = n.s. $r = .05$
Control group	p = n.s. $r = .04$		

Comparing these results with the reconstruction of the light-conception the effect sizes are smaller. Imaginative understanding seems to be more difficult to reconstruct. Therefore, only if the individual conceptions are considered and the metaphors concerning the *relations between object and eye* are explicitly reflected students will be able to reconstruct their everyday conceptions.

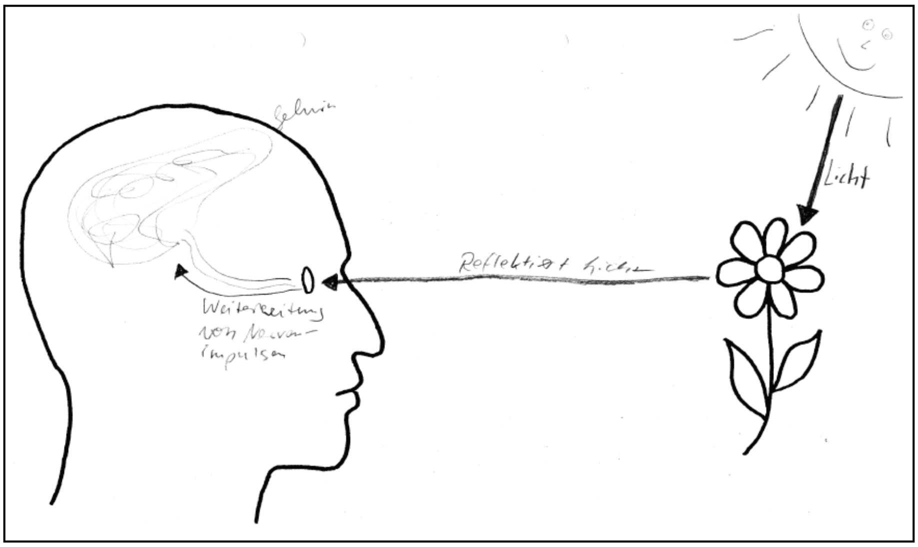

Figure 5. DR's drawing after the intervention (posttest), (text written down in the drawing from the right to the left side: light, reflects light, transmission of nerve impulses, brain).

The qualitative analysis of the students' comments on the learning material also shows this necessity of an explicit reflection of metaphors. DR has reconstructed his conception of "seeing rays" in the post- and in the follow up-test. He uses a science-oriented depiction: light shines on the flower and light is reflected from the flower into the eye (cf. Figure 5).

Another student (KJ) reflects his learning process as follows: "The ideas I mentioned before are not right, because the reflected light is falling into my eye and is not coming from the eye. There are no rays that enable us to see, there is only light that is directed into the eye." This exemplifies that students are able to reconstruct their conceptions using a start-path-goal-schema. This schema can be seen as a very helpful metaphor to understand what happens between the object and the eye in the process of seeing. But it has to be combined with the right "content", i.e. that the students need a conception of what is "moving" from the object into the eye. Therefore, the conception of the necessity of light should be reconstructed first.

5.4 An *image* is generated in the process of seeing – Imaginative understanding by using the *image*-analogy

This conception is the second example for imaginative understanding. The very common analogy "The eye is like a camera" which is often used at school is reflected in the learning material. Students that hold the epistemological conception of *everyday realism* often describe this conception.

Table 3. An *image* is generated– comparison of the results of the pre- and posttest, and the follow up-test (Wilcoxon)

	Pre-Post-Test	Pre-Follow up-Test	Post-Follow up-Test
Intervention group I	$p < .01$ $r = .33$	p = n.s. $r = .24$	p = n.s. $r = .28$
Intervention group II	p = n.s. $r = .17$	p = n.s. $r = .08$	p = n.s. $r = .16$
Control group	p = n.s. $r = .01$		

Looking at the statistical data it becomes obvious that just a few students of the intervention group reconstructed their conception of an *image*. The effect size is very small and the effect is lost in the follow up-test. This shows the difficulty to reconstruct the conception of an *image*.

What are possible causes for this difference? Firstly, the analogy of an *image* that is generated in the eye is often reconfirmed in biology and physics lessons in school: the camera is used as a model of the eye and the photo as a model of the experience we have while we are seeing. A problem is that the limitations and difficulties of this analogy are not reflected in most cases. More basic is that our experience itself seems to be analogue to a picture of our environment we have in mind. This also matches to the epistemological everyday conception of *everyday realism*: we see the world as it is. So 92 % of all students use metaphors of *images* to explain the process of seeing. They seem to be fundamental for our everyday understanding because of our self-experiences.

In this case, learning environments have to implement a conflict between the fundamental epistemological framework and our self-experience of seeing. Thus, the learning material was designed to offer a metacognitive critique of the *image*-analogy and explain the scientific conception. However, it was not offering an alternative analogy.

Some students successfully reconstructed their conception of an *image* even in the follow up-test. Qualitative analyses of their drawings and comments on the worksheets show what makes their reconstruction partly successful. Figure 6 shows RA's drawing from the posttest. RA did not reconstruct her conception of an *image* in the scientific way: she has not constructed the scientific conception that we cannot perceive the image on the retina. For her the *image* conception is still helpful but she is aware that this representation is just a model. She comments on her drawing: "There is no image but just electronic streams." Even in the follow up-test she is not drawing an *image*.

Other students formulated their metaconceptual awareness in phrases like "virtual image", "digital image" or "just a comparison or a model" after the instruction instead of "real image" that was often used before. Students do not find an alternative analogy that is plausible or fruitful for them to replace or reconstruct the *image* metaphor. But students are able to reconstruct their conception of an *image* if they can classify it as an analogy.

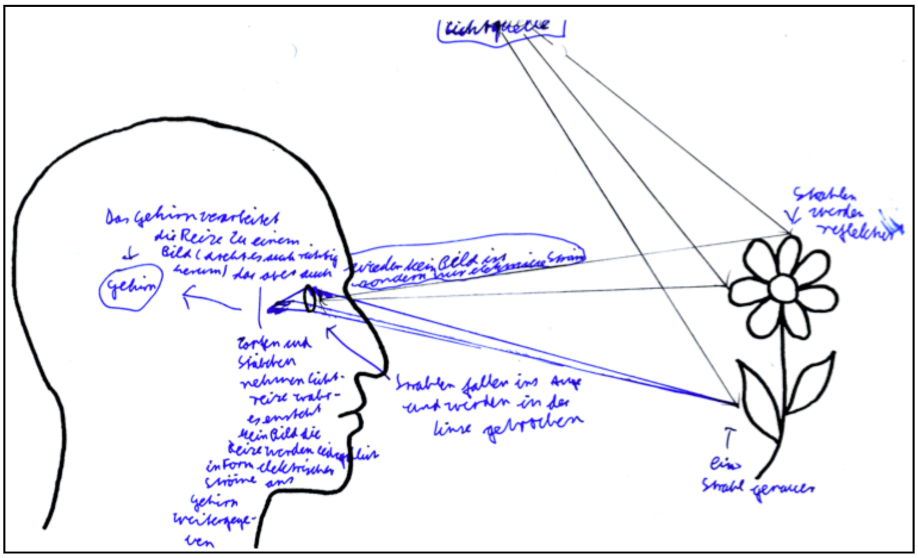

Figure 6. RA's drawing after the intervention (posttest), (parts of the text written down in the drawing from the right to the left side: rays are reflected, rays are reflected in the eye and are refracted in the lens, an *image* is not created but electronic currents are transmitted to the brain).

The described examples indicate that a key to scientific understanding is if individual conceptions, metaphors, and analogies are explicitly mentioned and reflected upon. In most cases students' results were significantly better if their individual conceptions were considered. Notably, abstract conceptions may only be reconstructed if the individual conceptions, metaphors, and analogies are mentioned.

5.5 Differences between different ways to gain understanding

In relation to the third research question, the data shown above shows differences between the different ways to gain understanding. If conceptions are experience-based, students can reconstruct them independently from the consideration of their individual conceptions. However, more students will reconstruct their conceptions if their individual conception is considered or reflected upon.

Conceptions of abstract phenomena that are based on imaginative understanding are only reconstructed if the individual conceptions and metaphors are reflected upon explicitly. The metaphor of start-path-goal can be seen as very helpful for a sustainable conceptual reconstruction.

Metacognitive awareness seems to be necessary to reconstruct very fundamental metaphors and analogies. The analogy of the *image* is correlated with the conception of *everyday realism* as an epistemological framing conception. That makes it very difficult to reconstruct. To enable students to reconstruct this conception it is necessary to strengthen phases of reflection in the learning material. Limitations and problems of this analogy have to be accentuated. This has to be taken into account to design a revised version of the learning material that will be tested in a following study.

6. Summary

In most cases the results of the students were significantly better if their individual conceptions were considered and reflected upon. Notably, in this study abstract conceptions were only reconstructed if the individual conceptions were explicitly mentioned.

The interpretation of students' metaphors and analogies shows that they can be the key to successful reconstruction of abstract conceptions under the condition that they are reflected upon explicitly. The metaphor of start-path-goal is a very helpful metaphor to understand the process of seeing. In contrast, the analogy of an *image* hinders scientific understanding.

Different ways to gain understanding influence the success of conceptual reconstruction: if direct experience is possible, students reconstruct their conceptions even if they are not explicitly reflecting on their individual conceptions. If imaginative understanding by metaphors or analogies is necessary, students in this study were only able to reconstruct their abstract conceptions if they were explicitly reflected upon.

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2 THE INTERPRETATION OF STUDENTS' LAMARCKIAN EXPLANATIONS

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Abstract

Some years ago we conducted a small scale design research study on the development of the concept of natural selection in upper secondary education. The results of this study were in contradiction with the results from other studies since hardly any Lamarckian explanations were found. In an attempt to explain these results we hypothesized that the occurrence of students' Lamarckian explanations is context-dependant, and that students construct these explanations instantaneously. So the question that required reconsideration was whether students' Lamarckian explanations should be interpreted as representations of available cognitive structures or as context-dependant instantaneous constructions.

Both interpretations were elaborated in an exploratory framework: a 'representation' framework, presuming that students hold stable and consistent conceptions, and a 'construction-in-interaction' framework, presuming that explanations are constructed in interaction, and that students rely on stable, previously acquired basic cognitive structures. This study focuses on the question which of the two frameworks explains the occurrence of students' Lamarckian explanations best. To answer this question, a number of studies reporting students' Lamarckian explanations were analyzed. Our analysis shows that all available empirical evidence can be explained by the 'construction-in-interaction' framework. Some educational implications are discussed in the final section.

1. Introduction

In the last decades, many research studies in science education reported on students frequently holding misconceptions or alternative conceptions. In biology education the best documented example of such a misconception is probably the Lamarckian conception. For a long time it was generally accepted that learning natural selection would require conceptual change of Lamarckian misconceptions (e.g. Bishop & Anderson, 1990).

Following the tradition of design research in Utrecht University, a small scale design research study was conducted (Geraedts & Boersma, 2006) presenting a stepwise development of the concept of natural selection. Data, collected before, during and after the intervention, showed that hardly any Lamarckian explanations. This result is in contradiction with results from many other studies, which reported a frequent occurrence of Lamarckian explanations (e.g. Bishop & Anderson, 1990) It was concluded that the occurrence of students' Lamarckian explanations is context-dependant, and that students construct these explanations instantaneously.

Enderle et al. (2009), in a critical rejoinder on our paper, claimed that 'an extensive body of literature […] has documented the existence and prevalence of a host of misconceptions in a wide array of fields, including Lamarckian misconceptions' (p.2528), and that '…recent pedagogy informed by conceptual change theory has resulted in as much as 50% of subjects achieving more scientific understandings of concepts where learning gains from using more traditional approaches are usually small or non-existent ...'(p.2529). These claims are so contradictory to our results that we were challenged to reconsider the literature mentioned, and address the question how to interpret students' Lamarckian explanations. Should these Lamarckian explanations be interpreted as representations of available cognitive structures or as context-dependant instantaneous constructions?

2. Conceptual framework

Based on the interpretation of the discrepant result of Geraedts and Boersma (2006) it was decided to elaborate two exploratory frameworks: a 'representation framework', presuming that students hold stable and consistent Lamarckian conceptions requiring conceptual change to acquire a neo-Darwinian conception, and a 'construction-in-interaction framework', presuming that Lamarckian explanations are constructed in interaction, and that students rely on stable, previously acquired basic cognitive structures. To avoid confusion, we will explain how the concepts 'conceptual change' and 'Lamarckian conception' are understood, before elaborating further these two conceptual frameworks.

2.1 Conceptual change

In Geraedts and Boersma (op.cit.) classical conceptual change theory was rejected, unfortunately without emphasising that different versions of conceptual change theory can be distinguished (e.g. Demastes, Good & Peebles, 1996; Duit & Treagust, 2003). For a proper understanding of conceptual change theory it is worth mentioning that the conceptual change theory, as introduced by Nussbaum and Novick (1982) and Posner, Strike, Hewson and Gertzog (1982), was considered an exponent of the so-called 'standard model of conceptual change', which focuses on how change or replacement of paradigmatic conceptual constructs like core concepts or theories can be accomplished. Although Posner et al. (1982) did not introduce conceptual change theory as an empirical prescription of how learning should be structured, many science educators and researchers applied it this way (Demastes et al., 1996). Consequently, many of them followed the original formulation of conceptual change theory, stating that '…learners must experience dissatisfaction with the original conception as well as judge a competing conception to be more intelligible, plausible and fruitful than the alternative in order for the new conception to be used in place of the old' (Demastes et al., op.cit., p. 408). It was this strategy, indeed, that was followed by Bishop and Anderson (1990) in the first conceptual change study in biology education.

Besides the standard model of conceptual change there is a broader view in which conceptual change is not understood as a process of replacement, but as a process of assimilation and restructuring. Duit and Treagust (2003) distinguish two types of conceptual change, variously called weak knowledge restructuring, assimilation or conceptual capture, and strong or radical knowledge restructuring, accommodation or conceptual exchange (p. 672). A good example of this broad view is presented by Demastes et al. (op.cit.), who recognize four patterns of conceptual change, of which only one corresponds with the standard model. In more recent theoretical contributions, the concept of conceptual change is defined at a finer grain size, not as the changes of a concept or conception, but as changes in a coherent set of propositions (diSessa, 2002). Özdemir and Clark (2007) distinguished two broad theoretical perspectives on conceptual change, a knowledge-as-theory perspective and a knowledge-as-elements perspective. This distinction shows the increasing interest in conceptual change at a finer grain size.

Summarizing, what was rejected was the standard model of conceptual change (diSessa & Sherin, 1998), focussing on changing or replacing worldviews or misconceptions by cognitive conflict, and not a conceptual change model that allows accumulation, differentiation, integration and restructuring of finer grained cognitive structures.

2.2 Lamarckian conceptions

To clarify the concept 'Lamarckian conception' we both have to discuss the nature of conceptions, and the criteria required to consider a conception as Lamarckian. We will discuss both issues successively.

Basically, a conception should be understood as a stable and consistent pattern of explanations (Taber, 2000). Consequently, students 'hold' a conception when such a stable and consistent pattern can be inferred from students' spoken or written expressions. For that reason a distinction should be made between students' conceptions and explanations, although most studies presenting empirical data report only on the occurrence of (Lamarckian) conceptions.

In Geraedts and Boersma (2006) explanations were only classified as Lamarckian if they involved individual organisms adapting to biotic or abiotic environmental factors during their lifetime *and* transmitting these changes to their offspring (p. 848). After all, when a student is talking about adaptation, it is often unclear whether he or she is referring to an organism adapting itself to new conditions, or just the species changing over time. Gregory (2009) distinguishes ‘soft inheritance’ (inheritance of acquired characteristics) from change due to use or disuse of organs, a view explicitly developed by Lamarck. Both categories were mentioned in the study by Bishop and Anderson (1990) and recognised as Lamarckian. Unfortunately, other studies do not always mention criteria to define Lamarckian explanations and it remains uncertain if an explanation classified as Lamarckian meets both criteria.

2.3 Explanatory frameworks

The idea to compare two explanatory models is not new. Southerland, Abrams, Commings and Anzelmo (2001) conducted a study which tested if students’ explanations for biological phenomena could be better explained by a so-called mental-model perspective, assuming the stability or consistency of students’ reasoning patterns, or a so-called ‘knowledge in pieces’ perspective based on diSessa’s p-prims, defined as spontaneous atomistic knowledge structures (diSessa, 1993). Unfortunately, the results of their study were not conclusive.

Özdemir and Clark (2007, p. 351) questioned if a student’s knowledge is most accurately represented as a coherent unified framework of theory-like character, or if it should be considered as an ecology of quasi-independent elements. They concluded that recent empirical evidence is supporting the knowledge-as-elements perspective, although they also recognise that there is support for a knowledge-as-theory perspective.

Empirical evidence supporting the knowledge-as-elements perspective was also found in some studies on the concept ‘force’ by diSessa, Gillespie and Esterly (2004) and Özdemir and Clark (2009). DiSessa et al. noticed that students’ answers were inconsistent across contexts, and that students’ understanding of force is context-dependant. It was concluded that these results support the idea that students’ knowledge consists of unstructured small elements that are unconsciously activated in certain circumstances. The study of Özdemir and Clark (2009) confirmed these results and showed that small contextual variations may affect students’ interpretation.

We will define the two explanatory models somewhat differently than Southerland et al. (2001) and Özdemir and Clark (2007). Both frameworks will be described in more detail to allow evaluatation of empirical data.

The first explanatory framework is the *representation framework*. It presumes that students (1) express a stable pattern of explanations that (2) must be interpreted as representations of available underlying cognitive structures. Thus, in this framework students’ Lamarckian explanations are considered as representations of a stable Lamarckian conception. It also predicts that students express consistent Lamarckian explanations.

The stability of students' explanations implies that conceptual change in the classical sense is required when their explanations are scientifically incorrect. This framework underlies the classical conceptual change studies mentioned before. In these classical conceptual change strategies a discrepant event is introduced to evoke dissatisfaction with the existing conception or cognitive conflict, before the introduction of the scientifically correct conception. It is emphasised that the new conception must be intelligible, initially plausible, and fruitful (Duit & Treagust, 1995, p. 62).

The second explanatory framework is the *construction-in-interaction framework*. This framework has two characteristics. It presumes that students (1) construct explanations in interaction that (2) are caused by activation of small, basic cognitive structures. The first characteristic, that students construct explanations in interaction with others (e.g. teachers and peers) and the environment, implies that '…students' explanations are understood to be fluid because they are constructed on the spot, in direct response to the very particular cues of the biological phenomenon and the interview question' (Southerland et al., 2001, p. 343). This first characteristic also implies that emergence of students' Lamarckian explanations may largely be determined by the context, in particular the context set by the teacher or researcher. Finally, it implies that students may construct Lamarckian explanations in one context, while in another context (or at another moment) alternative explanations are constructed.

The second characteristic of the construction-in-interaction framework is that students rely on stable, previously acquired basic cognitive structures that are triggered more or less unconsciously. In the aforementioned studies testing a 'knowledge-in-pieces' perspective, these basic cognitive structures are generally defined as p-prims (diSessa, 1993). In our view however, this is an unnecessary limitation, since literature shows that three empirically grounded approaches to basic cognitive structures can be found. The first approach then is described by diSessa (1993), who reports on the occurrence of fundamental knowledge elements, called phenomenological primitives or p-prims. P-prims are defined as atomistic knowledge structures that are automatically and unconsciously activated by the learner in response to a particular situation (diSessa, 2002).

A second approach on basic cognitive structures is found in the cognitive theory of Lakoff and Johnson (Lakoff, 1987; Lakoff & Johnson, 1999). It emphasizes that the mind is inherently embodied, i.e. that our basic conceptions originate from perception, body movement and experiences with the physical and social environment. Abstract concepts are largely metaphorical, drawing on the structure of our basic conceptions.

A third approach to basic cognitive structures can be found in the extensive experimental and theoretical studies in the field of developmental psychology. Many studies are devoted to categorization and basic concepts like causality, time, space and number. Literature shows that children acquire basic concepts such as causality at an early age, and that their performance improves during primary school age (Corrigan & Denton, 1996).

Explanations based on such pre-existing cognitive components are generally referred to as naïve explanations (e.g. Samarapungavan & Wiers, 1997). However, again we believe that this view is too limited while explanations may not only rely on small, basic cognitive structures but also on other previously developed and more or less consistent higher order cognitive structures. Consequently, the second explanatory framework does not even exclude a priori the possibility that students develop a Lamarckian cognitive structure.

An implication of this second characteristic is that there seems no reason to expect that available cognitive structures require conceptual change in the classical sense as long as students' small, basic cognitive structures are not in contradiction with the intended scientific concepts. That would imply that a successful learning and teaching strategy, based on gradual, stepwise conceptual development relying on these small, basic cognitive structures, may be interpreted as support for the second framework.

3. Research question

This study focuses on answering the following research question:

Which explanatory framework explains best the occurrence of students' Lamarckian explanations, the 'representation' framework or the 'construction in interaction' framework?

4. Methodology

The description of the two explanatory frameworks indicates that in order to decide which of the two frameworks best explains the occurrence of students' Lamarckian explanations, we have to focus on the following two partial questions:

1. What is the empirical evidence for the consistency of students' Lamarckian explanations?
2. What is the empirical evidence for the effectiveness of classical conceptual change strategies in changing or replacing Lamarckian conceptions?

4.1 The consistency of students' Lamarckian explanations

In order to make a selection of studies reporting Lamarckian explanations we selected first the publications on which Enderle et al. (2009) based their claims, then we consulted the references of these studies, and finally added a small number of other studies reporting students' Lamarckian explanations. Altogether, twelve studies were selected, including Geraedts and Boersma (2006) (see Table 3).

The conclusion that students' explanations are a manifestation of a conception is only warranted if these explanations demonstrate a consistent pattern. Following Taber (2000), a consistent pattern may be inferred if a student's line of reasoning is 'persistent over time and applied coherently across a wide range of overlapping contexts' (p.399). Therefore, we focused our analysis on the data on the consistency of individual students' patterns. Consequently, such patterns could not be inferred from studies recording percentages or numbers of Lamarckian explanations of a population of students. Therefore, we applied the scheme indicated in Table 1 for analysis of the data:

Table 1. Scheme for analysis of students' Lamarckian explanations

<table>
<tr><th>Step 1</th><th>Step 2</th><th>Step 3</th></tr>
<tr><td rowspan="5">Identification of data about Lamarckian explanations in the selected studies</td><td>Numbers or percentages of L. explanations of a population of students</td><td>(no further analysis)</td></tr>
<tr><td rowspan="4">L. explanations of individual students</td><td>Consistency across contexts (two contexts or more)_</td></tr>
<tr><td>Inconsistency across contexts (two contexts or more)</td></tr>
<tr><td>Consistency in time (two moments or more)</td></tr>
<tr><td>Inconsistency in time (two moments or more)</td></tr>
</table>

All data were analyzed by the first author. A selection of data was also analyzed by the second author. Comparison showed no discrepant results.

4.2 The effectiveness of conceptual change strategies

Five studies were found reporting results from classical conceptual change strategies in evolution (Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley, 1996; Jiménez-Aleixandre, 1992; Banet & Ayuso, 2003). Besides our own study (author 1) we found no studies that reported results from other strategies.

Conducting a meta-analysis comparing the effectiveness of classical conceptual change strategies with other strategies would require that only studies are selected that conduct an empirical evaluation of a conceptual change strategy and another alternative strategy with the same objectives and compare the outcomes of both strategies. Unfortunately, only the study of Demastes et al. (1995) meets this criterion. Furthermore, it was noticed that the five studies are rather diverse, i.e. in terms of test conditions, the age of the students, and the instruction methods that were used. Also, the results presented in two of the other four studies are rather incomplete.

A further limitation, linked up with the analysis of the consistency of students' explanations (see section 4.1), is that evidence for the effectiveness of a conceptual change strategy is only found when individual students demonstrate a pattern of Lamarckian explanations and abandon it in favour of a pattern of Darwinian or neo-Darwinian explanations. The only documented shift of a student from Lamarckian to Darwinian explanations was reported by Demastes et al. (1995). That implies that the other studies do not provide direct evidence for conceptual change. Comparing the outcomes of a group of students before and after instruction can only result in indirect evidence. Indirect evidence for the effectiveness of a conceptual change strategy is demonstrated when the percentage of Lamarckian explanations of a population of students decreases in favour of Darwinian or neo-Darwinian explanations.

Considering these shortcomings and limitations, we concluded that the available studies did not allow for a thorough meta-analysis. Therefore, we summarize only a short characterization of the studies and the conclusions about the effectiveness of the studies as presented by the authors of the studies themselves (see section 5.2).

4.3 Decision rules

We articulated a number of decision rules that were used in deciding which explanatory framework fits best with the empirical data (see Table 2).

Table 2. Decision rules

Criteria	Decision rules	
	Representation framework	*Construction-in-interaction framework*
Patterns of Lamarckian explanations	Evidence for consistent patterns of Lamarckian explanations	Evidence showing inconsistency or occasional consistency of Lamarckian explanations
Evidence for the effectiveness of classical conceptual change strategies	Evidence showing the adequacy of classic conceptual change strategies	Evidence showing the adequacy of strategies focusing on stepwise conceptual development

Occasional consistency of Lamarckian explanations indicates that some students or some populations of students may show a consistent pattern of Lamarckian explanations.

5. Results

5.1 The consistency of students' Lamarckian explanations

Our analysis (see Table 3) shows that five studies present percentages of explanations classified as Lamarckian in a population of students instead of the percentage of students giving consistent Lamarckian explanations. Only three studies were found reporting the consistency of students' Lamarckian explanations, although no consistency in time was reported.

Table 3. Consistency of Lamarckian explanations in the selected empirical studies

	Population of students	Individual students		
		Inconsistent	Consistent across contexts	Consistent in time
Brumby (1979)			X	
Kargbo et al. (1980)			X	
Clough & Driver (1985)		X		
Clough & Wood-Robinson (1985)		X		
Halldén (1988)		X		
Bishop & Anderson (1990)	X			
Jiménez-Aleixandre (1992)	X			
Demastes et al. (1995)	X			
Jensen & Finley (1996)	X			
Samarapungavan & Wiers (1997)			X	
Banet & Ayuso (2003)	X			
Geraedts & Boersma (2006)		X		

Two studies (Clough & Driver, 1985; Samarapungavan & Wiers, 1997) focused explicitly on the consistency of students' evolutionary explanations. The results of both studies, however, are contradictory. Clough and Driver reported a low overall level of consistency across contexts. Samarapungavan and Wiers found that 28 out of 35 interviewed primary school children showed consistent explanatory patterns, among which, however, only three were identified as Lamarckian, while most of the children showed consistent non-evolutionary patterns. Inconsistent explanations were also reported by Halldén (1988) and Clough and Wood-Robinson (1985).

The results about the consistency of students' Lamarckian explanations are not conclusive. There is no doubt that Lamarckian explanations are frequently reported. But only three out of ten studies reported students showing consistency of Lamarckian explanations across different contexts. Consistency in time was not demonstrated in any study. On the other hand, four studies explicitly reported on the inconsistency and context-dependence of students' explanations.

5.2 The effectiveness of conceptual change strategies

Bishop and Anderson (1990) reported the results of a pretest-posttest study among college students following an introductory biology course with instruction inspired by conceptual change theory. Although the presentation of data was rather incomplete, it was concluded that the percentage of students able to use the scientific conceptions to explain evolutionary changes increased from less than 25% to over 50%. The authors concluded from these data that their course was moderately successful (p. 415).

The study of Bishop and Anderson was replicated by Demastes et al. (1995) by comparing the results of students following the conceptual change strategy with those of a group of students receiving traditional instruction. The difference between the results of both groups was not significant: both '…methods of instruction failed to promote the construction of a scientific conception' (p. 541).

Jiménez-Aleixandre (1992) reported that significant differences between two groups of students following different conceptual change strategies were found in posttest and retest. Unfortunately however, data of the pretest are hardly reported and pretest, posttest and retest questions are only partly similar. Furthermore, the number of Lamarckian and Darwinian explanations was not presented.

Jensen and Finley (1996) reported the results of a study comparing the results of four different classical conceptual change strategies. If the shift of Lamarckian to Darwinian expressions is considered, the data indicate that the change scores between pretest and posttest varied between 6 and 12 %.

Finally, the most successful study following a traditional conceptual change strategy is presented by Banet and Ayuso (2003). In a pretest, posttest and retention test design the learning outcomes of 14-16 year old students following a course in genetics and evolution was measured. An increase of Darwinian explanations from 8 to 70 %, and a decrease from 86 to 14 % Lamarckian explanations was recorded. In the retention test the number of students presenting Darwinian explanation decreased again to 52 %.

Summarizing, only the study of Banet and Ayuso presents results of a successful classical conceptual change strategy. Their results are comparable with the results of Geraedts and Boersma (2006), showing that 72 % of the students gave consistent neo-Darwinian or Darwinian explanations.

6. Conclusion and discussion

6.1 Conclusions

From our analysis, the following inferences can be made:

1. Empirical evidence for consistent patterns of Lamarckian explanations is not conclusive. Some studies demonstrated consistency, but not consistency in time, while other studies demonstrated inconsistent and context-dependant Lamarckian explanations. The inconsistency of these results can be explained by the construction-in-interaction framework, since it accepts context-dependence.
2. Most classical conceptual change studies reported limited to modest results. The results of the only successful classical conceptual change study are similar to the outcomes of Geraedts and Boersma (2006). Consequently, it should be concluded that there is no evidence that conceptual change strategies are more effective than traditional strategies.

Comparing these results with the decision rules (see Table 1) it can be concluded that the available empirical evidence can be explained by the construction-in-interaction framework and that the representation framework has only a limited explanatory potential.

6.2 The occurrence of students' Lamarckian explanations

Although our analysis shows that there is not sufficient evidence to support the consistency of students' Lamarckian explanations, the question remains why so many students construct Lamarckian explanations in interaction. To answer this question, both internal and external conditions have to be considered, since our model predicts construction in interaction.

From the literature we derived three critical internal conditions for the occurrence of Lamarckian explanations: (1) students' limited experience with evolutionary phenomena (Samarapungavan & Wiers, 1997), (2) students' lack of understanding of the mechanism of sexual inheritance (Kargbo et al., 1980), and (3) students' lack of understanding of the concepts 'population' and 'species' (Halldén, 1988). However, it seems that the occurrence of Lamarckian explanations cannot be explained satisfactory by missing cognitive structures. It may be expected that we have to search for more specific external cues, triggering basic cognitive structures.

Although details about the researchers' questioning behaviour are not reported, some possible external effects may be inferred from the nature of the questions. Questions from studies like Kargbo et al.(1980), related to the effects of external factors on the offspring, show that (1) researchers' questions tend to describe a possible phenomenon occurring in daily life (i.e., the questions are not set in an evolutionary context), (2) the questions deal with inheritance and not with an evolutionary phenomenon, (3) the phenomena presented are not related to the level of the population, and (4) the question itself already suggests that there is an effect on the offspring, which makes it difficult for a student to contradict it.

6.3 Implications for conceptual development

A major implication of the 'construction in interaction' frameworks for conceptual development is that there is no need for conceptual change according to a traditional conceptual change strategy. The framework predicts that students' explanations may emerge by external activation of basic conceptual components. Consequently, students may construct neo-Darwinian explanations under appropriate conditions that activate their interconnected basic conceptual components and to build up from there, until students are able to construct neo-Darwinian explanations for evolutionary phenomena, in different contexts. A metaphor for such a pattern of constructions can be found in dynamic systems theory as elaborated in developmental psychology (Thelen & Smith, 1994), in which the term attractor is used to indicate a behavioural pattern.

An important question that remains open for further investigation is what the nature is of these building blocks that can be used as starting points for conceptual development, and how a sequence of fine-grained steps can be elaborated. A preliminary answer to this question is found in diSessa's idea of coordination class (diSessa, 2002), consisting of a network of interconnected p-prims. If we extend the idea of p-prims to all propositions the development of the concept of natural selection can be based on a sequence of interconnected propositions from a concept map that represents the concept of natural selection accurately. A comparable procedure is followed in some recent PhD-studies (e.g. Wierdsma, 2012).

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3 EFFECTS OF EXPERIMENTS FOR STUDENTS' UNDERSTANDING OF PLANT NUTRITION

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Abstract

The experiment is important in biology classes. It is associated with many objectives. But what role does it play in the development of science-related conceptions for plant nutrition? Plant nutrition is part of a scientific education. Students often find it difficult to understand. Many of them hold pre-existing conceptions which are not in line with the generally accepted scientific view. The aim of this study is to clarify whether experiments which are embedded in a constructivist learning environment support the development of more scientific ideas. It also examines whether doing experiments has got an effect on emotional aspects such as interest or motivation.

279 students at the entry-level of secondary education participated in the study. A written test was constructed to capture the students' conceptions about plant nutrition in the pre-post design and a follow-up. The emotional aspects were collected by a questionnaire in the pre-post design. The students got a treatment which consisted of a teaching unit on plant nutrition. It was embedded in a learning environment in which many or no experiments were done. The results show that an experimental experience supports a conceptual change with a long lasting influence.

Keywords: experiments, plant nutrition, constructivism, conceptual change, secondary school

1. Introduction

It is generally agreed that students bring certain ideas and phenomena to science lessons which are well established in their ways of thinking. But many of these pre-existing conceptions are incompatible with currently accepted scientific knowledge (Duit, 2003). They are often resilient and difficult to change by teaching. Many of these conceptions are proved in everyday life. This can be one reason of profound learning difficulties. New aspects are based on what is already known (Duit, 1993). To consider students' conceptions is therefore essential for subsequent learning.

1.1 Existing research

Intensive research on students' conceptions about plant nutrition took place in the 1980s. Most of the research was done in Anglo-American countries. Recent studies are hardly present. Most of the existing works are exploratory cross-sectional studies. They focus students' conceptions about plant nutrition after science teaching (e.g. Haslam & Treagust, 1987; Stavy et al, 1987). The results of these studies show two similarities. On the one hand they show that students think that plants absorb their nutrients from the environment, especially from the soil. Students often do not understand that plants are autotrophic organisms. On the other hand almost all the studies show that it is very difficult to change the pre-existing conceptions despite science teaching.

Although the topic of plant nutrition plays an important role in science lessons at secondary school, the development of students' conceptions based on methodically and didactically coordinated teaching modules is hardly found in the existing research.

1.2 Theoretical background

There is agreement among education scientists that the adoption of appropriate scientific conceptions is a constructive process. The constructivist approach is seen as a perspective for understanding, interpreting and influencing student learning in science (Hewson & Thorley, 1989). It recognizes the influence the pre-existing experience has on the way phenomena are perceived and interpreted and emphasises the active construction of meaning (Driver & Oldham, 1986). Such constructivist learning environments are based on authentic problems and direct experience. They enable students being active as well as discovering new explanations. They are also characterised by emotional involvement and self-regulated learning (Gerstenmeier & Mandl, 1995; Driver & Oldham, 1986). A typical learning environment of this kind encourages activities like experimentation. While planning and conducting experiments students are confronted with challenging and authentic tasks. They are able to self-regulate their learning as well as to generate explanations.

But up to now it is not clarified what role experiments actually play in the process of conceptual change. Research results demonstrate that pre-existing conceptions cannot be abolished easily and replaced by scientific ones (e.g. Haslam & Treagust, 1987; Stavy et al, 1987). But how to initiate the process by which such changes occur? According to Strike and Posner (1992) a conceptual change is based on four conditions: dissatisfaction, intelligibility, plausibility and fruitfulness. The idea of conceptual change is not to extinguish and replace the pre-existing conceptions. Furthermore, the aim of science teaching should be to make students aware that in scientific contexts the scientific conception is more viable than the everyday conception (Treagust & Duit, 2008).

2. Questions

According to the theoretical models and the analysis of previous research the following questions were examined.

1. What kind of role do experiments play in the development of scientific conceptions about plant nutrition?
2. Do students experience the emotional aspects of a constructivist environment better when it attaches importance to experiments or when it does not?

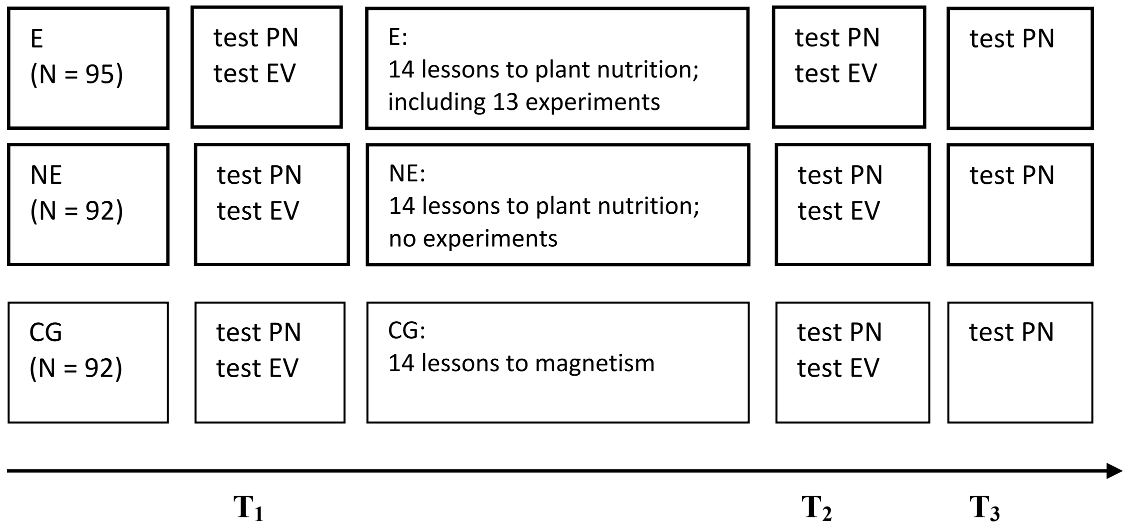
3. Work plan

3.1 Sampling

In the present intervention study two teaching concepts about plant nutrition were developed. They were embedded in a constructivist environment. One of the learning environment included experiments (E) the other did not (NE). There was also a control group (CG) to capture the overall effect of the treatment as well as the methodological artifacts. The students in the control group did not deal with the topic of plant nutrition. They got lessons to the topic of magnetism. The investigation took place in the subject of Science. It involved nine school classes (N= 279) at the entry-level of secondary education. They came from two different schools. The students were 11-12 years old. The classes were randomly assigned to the experimental groups and the control group (cluster sample). Each group included three school classes ($N_E = 95$; $N_{NE} = 92$; $N_{CG} = 92$).

3.2 Instruments

The study was organized as a repeated measures design (Figure 1). With the help of a questionnaire the students' conceptions about plant nutrition were collected. The questionnaire was used three times in all the groups. The pretest took place before the intervention started. The posttest was handed out right after finishing the treatment. The follow-up-test took place after ten weeks. The questionnaire included a total of fourteen tasks with open and closed answer format. The tasks were embedded in situations which were not treated in the classroom. The alternative answers to the closed questions were generated using group interviews. The tasks were scored and a total value was generated. (Cronbach's α [pretest, posttest, follow-up test] = .43, .90, .91).



test PN: test plant nutrition
test EV: test emotional variables

Figure 1. Work plan.

The written test instrument to the emotional variables was adopted and modified from Blumberg (2008). It was handed out to all the groups as a pre- and posttest. At the posttest the instrument was used in an expanded form. The scales, the number of items and the reliabilities are shown in Figure 2. The response scale for all the items was a four-point Likert-Scale (1 = lowest approval; 4 = highest approval).

Scales (number of items)	**α (pretest)**	**α (posttest)**
interest (11)	.92	.94
non-school related interest (5)	.75	.83
intrinsic motivation (5)	.80	.88
extrinsic motivation (4)	.64	.74
self-efficacy (6)	.84	.86
self-concept (3)	.87	.87
feeling of being successful (6)	---	.91
feeling of being competent (7)	---	.89
importance of the lessons (8)	---	.91
autonomy (14)	---	.92

Figure 2. Emotional variables (scales, number of items, reliabilities).

The data were examined by the analysis of variance to see the effect of the treatment. Furthermore, the individual items of the students' conceptions to plant nutrition were analyzed using frequencies and the non-parametric Friedman-Test (see Field, 2009). The aim was to determine the conceptions of the students to the different points in time and to find out how they developed within the experimental groups and the control group.

3.3 Lessons

The teaching concepts in the two experimental groups consisted of fourteen lessons on plant nutrition. The lessons can be grouped into five thematic blocks: nutrients and energy, living conditions of plants, water balance in plants, air composition as well as photosynthesis and solar energy. The blocks did not only focus on plant nutrition. They also integrated other scientific conceptions which support an understanding of the process (e. g. water balance in plants). The students in the experimental group E usually did one experiment in each lesson. They worked in groups of three to four students. Very important was that the experiments were not repeated just like a recipe in a cookbook. The groups had to find a research question and to plan and carry out the experiment independently. The materials were provided by the teacher. There were thirteen experiments altogether. The students in the experimental group NE did not do any experiments on their own. Only two experiments were demonstrated by the teacher. The students also worked in small groups. They used illustrations, texts, models or film sequences instead. (Example: While the students in the experimental group E tried to find out what influences the photosynthesis rate with the help of an experiment, the students in the group NE watched a film to that topic.)

The content of the lessons, the chronological sequences of the lessons as well as the teacher were identical in both groups. The teacher was not the subject teacher of the students. It was an external person. The lessons in both groups were embedded in a constructivist learning environment. So the students were enabled and encouraged being active, discovering new explanations and find their own path of successful learning. It was also given enough time and space to discuss the ideas with classmates and to review and reflect them. Results were recorded, interpreted and compared with the previously expressed conceptions. The students' conceptions were visualized throughout the unit and presented by the teacher again and again. This should help the students to think about existing conceptions and to develop adequate ones. The only difference in the two experimental groups was the experiment. Whenever the students in the experimental group E did an experiment, the students in the other group NE worked with an alternative.

The students in the control group (CG) did not deal with plant nutrition at all. The topic of their lessons was magnetism. The teachers were instructed to teach as they usually do. The lessons were not embedded in a constructivist environment. The teachers were the subject teachers of the students.

4. Results

The analyzed data show that the groups do not differ at the beginning of the intervention (Figure 3). If you put the focus on the control group (CG) you can see, that the arithmetic mean is quite low and almost constant at all the three points in time. That is different in the two experimental groups. The descriptive data indicate an increase in learning.

Regarding the effects of the intervention the repeated measures analysis shows a significant interaction effect ($F(2, 275) = 10.45$, $p \leq .001$, $\eta^2_p = 0.71$) and group effect ($F(2, 275) = 363.84$, $p \leq .001$, $\eta^2_p = .726$). The total value of the post- and follow-up tests to the students' conceptions about plant nutrition was used for it. The data of the pretest were considered as a covariate. This result indicates that the groups develop differently over the time and that the differences remain even after removing the data of the pretest.

		M (SD)	
measuring time	**E** **(N = 95)**	**NE** **(N = 92)**	**CG** **(N = 92)**
t_1	4.17 (2.64)	3.96 (2.91)	3.66 (2.37)
t_2	20.06 (5.56)	18.12 (5.67)	3.80 (2.40)
t_3	21.52 (6.00)	17.15 (6.35)	3.76 (2.72)
scale 0-34 (test results)			

Figure 3. Descriptive data of the scale to the students' conceptions about plant nutrition.

A detailed look at the two experimental groups with the help of the analysis of covariance shows a significant group effect in the posttest ($F(1, 183) = 4.19$, $p \leq .05$, $\eta^2_p = .022$) and in the follow-up test ($F(1, 183) = 20.85$, $p \leq .001$, $\eta^2_p = .102$). The significant effect is in favour of the experimental group E (Figure 3). Immediately after the intervention the difference between the two experimental groups only shows a small effect. But ten weeks later a quite strong effect is recognizable. The descriptive data indicate that the treatment has affected the memory performance of the students in different ways (Figure 3). The arithmetic mean of the experimental group E is in the follow-up test higher than in the posttest. This can indicate that the students developed more adequate conceptions. In the experimental group NE it is just the other way round. The children there seem to forget some of the established science-related conceptions.

If you have a closer look at the students' conceptions you can see that they have many different conceptions about plant nutrition at the entry-level of secondary education. The analysis of the individual items in the pretest shows, that the children often assume that plants absorb their nutrients from the environment. An example out of the questionnaire to the students' conceptions about plant nutrition illustrates this (Figure 4).

How does the sugar get into the fruit?				
	pre frequency %	**post** frequency %	**follow-up** frequency %	**Friedman-Test**
Through minerals from the soil, the fruit is sweet.				
E	52	7	4	p ≤.001
NE	55	7	7	p ≤.001
CG	53	50	47	p = n. s.
The plant takes the sugar from the soil.				
E	33	8	5	p ≤.001
NE	37	3	10	p ≤.001
CG	44	41	41	p = n. s.
Honeybees make the fruit sweet.				
E	24	1	1	p ≤.001
NE	25	1	1	p ≤.001
CG	28	24	29	p = n. s.
The fruit is sweet due to the growth of its own.				
E	27	10	3	p ≤.001
NE	20	4	1	p ≤.001
CG	37	34	36	p = n. s.
The water the plant absorbs contains sugar.				
E	17	3	0	p ≤.001
NE	19	2	2	p ≤.001
CG	17	22	19	p = n. s.
The plant produces the sugar in the leaves.				
E	15	81	84	p ≤.001
NE	21	73	84	p ≤.001
CG	17	27	25	p = n. s.

Figure 4. An example out of the questionnaire to students' conceptions about plant nutrition.

Conceptions where the soil plays an important role are quite dominant in the pretest. About half of the students think that fruits are sweet through minerals from the soil. More than a third assumes that the plant absorbs the sugar from the soil. The development of the percentage frequencies shows that at the post- and follow-up-test fewer students of the experimental groups use these inadequate conceptions (Figure 4). This can also be observed with the other conceptions which are not in line with the scientifically accepted view. On the contrary, the scientifically accepted conception (plans produce the sugar in the leaves) is evident in the two experimental groups. There is an increase to over eighty percent. In the control group (CG) this development is not visible. This is manifest in the results of the Friedman-Test. In the control group (CG) the results are not significant, in the experimental groups they are (Figure 4). The students in the experimental groups are usually able to understand the process of plant nutrition, its importance and the fundamental factors. They are also able to develop scientific conceptions. This development cannot be observed in the control group (CG).

The analysis of covariance to the emotional aspects shows that eight out of ten scales have significant group differences (Figure 5).

scale (1-4)	M (SD) E (N = 95)	NE (N = 92)	CG (N = 92)	group effect
interest	3.23 (.69)	3.18 (.64)	3.08 (.72)	$F(2, 273) = 3.79$; $p \leq .05$; $\eta^2_p = .027$
non-school related interest	2.06 (.69)	2.22 (.80)	1.99 (.58)	$F(2, 273) = 3.57$; $p \leq .05$; $\eta^2_p = .025$
intrinsic motivation	3.01 (.83)	3.19 (.75)	2.87 (.82)	$F(2, 273) = 5.39$; $p \leq .01$; $\eta^2_p = .038$
extrinsic motivation	2.27 (.75)	2.46 (.88)	2.49 (.68)	$F(2, 273) = 1.37$; $p =$ n. s.; $\eta^2_p = .010$
self-efficacy	3.26 (.65)	3.31 (.55)	3.17 (.64)	$F(2, 273) = 3.63$; $p \leq .05$; $\eta^2_p = .026$
self-concept	2.69 (.67)	2.76 (.69)	2.69 (.58)	$F(2, 273) = 1.48$; $p =$ n. s.; $\eta^2_p = .011$
feeling of being successful	3.19 (.74)	3.14 (.73)	2.70 (.78)	$F(2, 273) = 20.87$; $p \leq .001$; $\eta^2_p = .133$
feeling of being competent	3.01 (.67)	3.09 (.73)	2.92 (.71)	$F(2, 273) = 3.77$; $p \leq .05$; $\eta^2_p = .027$
importance of the lessons	2.99 (.75)	2.99 (.76)	2.66 (.77)	$F(2, 273) = 10.86$; $p \leq .001$; $\eta^2_p = .074$
autonomy	3.08 (.65)	2.90 (.68)	2.31 (.61)	$F(2, 273) = 42.51$; $p \leq .001$; $\eta^2_p = .237$

Figure 5. Descriptive data and test statistics of the scales to the emotional variables (posttest).

Contrasts, which compare the mean values of the experimental groups with the mean values of the control group, pointed out that the experimental groups differ from the control group. It is most clearly at the variable of autonomy. Here you can find a very strong effect (Figure 5). The variables of extrinsic motivation as well as the ability to self-concept turn out to be stable characteristic values. The comparison between the experimental group E and the experimental group NE only shows a significant difference relating to the variable of autonomy ($F(1, 184) = 4.12$, $p \leq .05$, $\eta^2_p = .022$). It is in favour of the experimental group E. The learners in the experimental group E obviously feel more independent than in the classroom than the students in the experimental group NE do.

5. Summary and Discussion

The results show that students at the beginning of secondary school have a number of different conceptions about plant nutrition. They do often not agree with the science-related conceptions. Very dominant is the idea that plants absorb their food from the environment. The conception that plants synthesize their nutrients itself is hardly represented. This corresponds with previous research findings (e.g. Eisen & Stavy, 1988; Bell, 1985; Marmaroti & Galanopoulou, 2006). This idea is clear and also supported by the experience of the learners. Human beings absorb food as well as animals. This can be observed in everyday life. So it is not surprising that students think that plants absorb their nutrients from the environment as well.

The results in the present study show that students are able to develop scientific conceptions about plant nutrition. Numerous studies which determined the learners' conceptions after science teaching could not or only hardly notice that (e.g. Haslam & Treagust, 1987; Marmaroti & Galanopoulou, 2006). However, the results also show that the teaching in the learning environment with experiments is superior to the teaching in the learning environment without any experiments. It is especially obvious in the long term effect. The learners in the group with no experiments tend to forget science-related conceptions in the course of time. In the group working with experiments an increase can be observed.

One possible explanation to that phenomenon gives the theory of cognitive load (Sweller, 1994). It emphasizes the important function of the working memory. Its capacity is considered to be limited in the processing of new information. The success in the experimental group E is obviously based on the capacity of the working memory. Doing experiments is complex. It requires cognitive, affective, psychomotor and social skills. At the time of the posttest the working memory is apparently strained. After a period of ten weeks, however, a further development of science-related conceptions can be observed by the learners who did the experiments. Possibly there was a transfer of information into the long-term memory. The present results suggest that self-experimentation helped the learners to anchor information more deeply.

Regarding the results of the emotional aspects the study shows that the experimental groups do not differ at all – apart from one exception. Only the experience of autonomy differs in favour of the students who worked with experiments. The feeling of making own decisions, developing own ideas or planning one's action is obviously more noticed in that group. Self-directed learning is important to anchor knowledge (Schiefele & Streblow, 2005). This may also explain the rise of scientific conceptions from the posttest to the follow-up-test.

No matter whether the learning environment included experiments or not – there were many positive emotional effects in both experimental groups. This result suggests that experimentation in the classroom does not necessarily lead to a higher motivation or greater interest as often postulated in science teaching. Apparently it is more important that the lessons are embedded in a learning environment which supports the development of these emotional aspects. The constructivist learning environment in the present study obviously offered that chance.

The study is based on a quasi-experimental design with a relatively small sample. Therefore you have to be careful to generalize the results. It is important to replicate the findings.

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4 CHANCE AND DETERMINISM IN EVOLUTION: TEACHERS' CONCEPTIONS IN 21 COUNTRIES

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Abstract

While stochastic processes are central in biology, they have only recently begun to be introduced at school, where biology is often associated with deterministic processes.

To analyze teachers' conceptions of the role of determinism and chance in evolution, we conducted a large survey in 21 countries: 8078 in-service and pre-service teachers (in Primary Schools and in Secondary Schools teaching biology or language) filled out the BIOHEAD-Citizen questionnaire, including 14 questions on Evolution and 17 on personal opinions.

We found important differences among the countries. While the importance of natural selection in species evolution is widely accepted, it is not the case for chance. When chance is not associated with evolution (*When a couple has already had two girls, the chances that their third child be a boy are higher*), more teachers recognize the role of chance. On the contrary, a significant number of teachers think that God is very important or important in species evolution. Nevertheless, several of them (particularly biologist teachers) are simultaneously evolutionist and creationist.

In half of the countries, we found significant differences between biologist teachers and their colleagues, biologist teachers being more convinced of the importance of chance, natural selection and evolution.

Key words: Chance, Evolution, Creationism, Teachers' Conceptions, International survey.

1. Biological topic

Since Descartes (17th Century), living organisms have been compared to machines. Creationist publications reproduce this way of thinking, comparing any organism with a machine such as a watch and claiming that they know the watchmaker (God).

Darwinism (and subsequently neo-Darwinism) contradicts this determinist point of view. Stochastic processes are involved in the differentiation of new structures, which are then selected by natural selection, or conserved as neutral.

Furthermore, new trends in biology promote the idea of a cellular Darwinism (Kupiec 2008; Kupiec et al., 2009): during embryonic development, each cell fluctuates randomly between different states and stabilizes according to its interactions with neighbouring cells, by natural selection. From the growing number of new data in biological research showing the key role of stochastic processes, several authors suggest "*the end of determinism in biology*" (Paldi & Coisne, 2009), and philosophers are distinguishing several kinds of determinism (Gayon, 2009).

The philosopher of biology Gayon (1997) defined three categories of meanings for the concept "hasard" (in French), more or less corresponding to the concept of "chance" in English: (1) An unpurposed and unpredictable event, without design but which can be *a posteriori* useful. (2) A chancy event, by random, but which can be predictable by the laws of probability. If you toss a coin, it will fall by chance on its "head" or on its "tail". If you toss it 10 000 times, it will fall on its head 50% of the time and 50% on its tail: this result is predictable and reproducible. (3) Fortuitous events, by chance because they are not predictable inside a theory, they are too complex: chance is here contingent to a theoretical system.

Concerning the five levels of biological evolution, mutations and macro-evolution are related to the meaning (1), the genetic drift with the meaning (2) and the levels of genome as well as of ecosystems with the meaning (3)

Consequently, linked to the meaning (2), chance does not mean lack of reproducibility: random events at the molecular level may lead to cellular structures that are ordered and reproducible. Early in 20th Century, quantum physics, with the principle of Heisenberg, showed that stochastic processes produce apparent order in physical and chemical phenomena. At the same time, taught biology became more determinist, taught genetics being mainly been centred on the determinism of the phenotype by the genotype (Forissier & Clément, 2003; Castéra et al., 2008; Clément & Castéra, 2013). This reductionist view has decreased since the end of 20th Century with "*the end of everything is genetic*" (Atlan, 1999), the notions of cerebral epigenesis (also called Neuronal Darwinism: Changeux 1983, Edelman, 1987) and of epigenetics (interaction between genes and their environment to explain the emergence of phenotypes: Lewontin, 2000; Jacquard & Kahn, 2001; Wu & Morris, 2001; Morange, 2005). The present revival of creationist views, including the intelligent design, is a return to the past, promoting deterministic explanations that are out-dated in biology. Today, the neo-Darwinian explanation of evolution is not only accepted but also considered as central in biology (Dobzhansky, 1973).

Our goal is to analyse if these new paradigms in biological research are now being introduced in biology teaching. Biological knowledge is universal, but the way it is taught is often different, depending of the social context and the teachers' values. We will analyse this interaction between taught science and society, using a comparative approach among several contrasting countries.

2. Theoretical background

We analyze here teachers' conceptions, because teachers are a key step in the didactic transposition of new knowledge at school (Chevallard, 1985; Clément, 2006). We are particularly interested in the DTD (Delay of Didactic Transposition: Quessada & Clément, 2007), i.e. the delay between the emergence of new concepts in research (Darwinian processes, importance of chance, decrease of determinist views, …) and their introduction into the taught science.

We can define four types of DTD, if we analyze: (1) the syllabuses, (2) the textbooks, (3) the teachers' conceptions and (4) the sequences of teaching. The syllabus and textbooks have already been analyzed in several countries for the topic Evolution (e.g. Quessada et al., 2008; Quessada, 2008): they are still to be analyzed concerning a clearer presence of stochastic processes. Sequencing by teachers is analyzed in some countries, such as Tunisia where teaching evolution is problematic (Aroua, 2008). The present paper analyzes only the teachers' conceptions in several countries.

We used four levels of conceptions (Clément, 2010, Table 1):

- Situated conception, expressed by somebody in a precise situation (here each question of the used questionnaire).
- Conception, as the convergence of several situated conceptions (here the convergence from a set of questions dealing with the same topic).
- Social representation (Moscovici, 1984) when the same conception is held among the members of a social group (also called collective representation by Durkheim, 1889).
- System of conceptions when there is a significant correlation between several social representations.

Table 1. Different types of conceptions, explained for the analysis of answers to a questionnaire (translated from Clément, 2010, and modified)

	Individual level	**Collective level**
Situated Conceptions	When somebody answers to a precise question in a precise situation (as a question of a questionnaire)	When several persons, placed in a precise situation, answer in the same way (e.g. answer identically to a precise question of a questionnaire)
Conceptions related to a topic	When somebody answers with coherence to several questions (= different situations) related to the same topic	When the individual conceptions related to a topic are shared inside a social group: "**social representations**" (Moscovici 1984), "Collective representations" (Durkheim 1898)
System of conceptions	When several conceptions (social representations) are correlated, or are correlated with political, social or religious opinions (e.g. the Principal Component in a PCA, or in a Co-Inertia Analysis)	

We also use the KVP model (Clément, 2004, 2006, 2010), to analyze these conceptions as possible interaction between scientific knowledge (K), Values (V) and social practices (P).

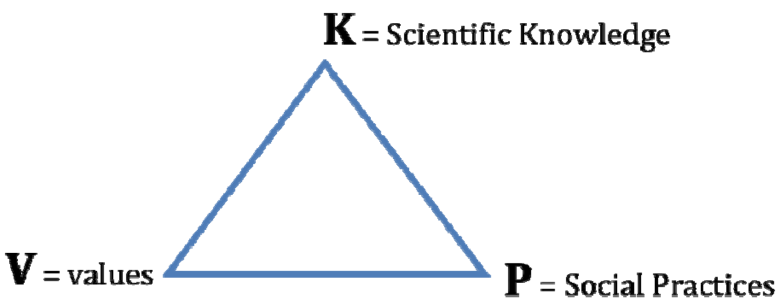

Figure 1. The KVP model (translated from Clément, 2004).

For instance deterministic conceptions can be supported by out-dated scientific knowledge (K) but also by values (V) as fatalism, and social practices (P) as housekeeping by women and not by men.

3. Key objectives

We focus the present work on teachers' conceptions related to the role of chance and determinism in the evolutionary processes. The degree of acceptation or reject of creationism (as a deterministic process of evolution) is compared to the degree of considering the importance of some processes of evolution as chance and natural selection.

The possible interaction between the teachers' conceptions and their national socio-cultural context is analyzed by a comparison among different countries.

Related to the KVP model, we mainly identify if the teachers' scientific knowledge is up-to-date or out-dated, trying to understand the resistance of some out-dated knowledge if rooted in values and practices. In each country, we compare the conceptions of teachers trained in biology at University, with conceptions of their colleagues, to identify the possible effect of teachers' training in biology.

4. Research design and methodology

We used a long questionnaire, built by the BIOHEAD-Citizen project (*European Research Project*: Specific Targeted Research n° CIT2-CT2004-506015, FP6, Priority 7), tested and validated over two years (Clément & Carvalho, 2007). Here, we use the answers to two sets of questions: on Evolution (14 questions), and on personal political or religious opinions (17 questions: for instance the question P12b, illustrated below in the Figure 7).

The 14 questions related to Evolution have several goals:

- To identify if the teachers' conceptions are more or less creationist (evolution being determined by God) or evolutionist (only natural processes): 5 questions (including B48 and B28 illustrated by the Figures 6 and 7), with the possibility, e.g. in the question B28 (Figure 7) to tick the item 3 which is at the same time evolutionist and creationist. In this last question, the items 1 and 2 are evolutionist, the first one being more dogmatic while the item 2 is mentioning God ("…*without considering the hypothesis that God created humankind*").
- To identify if, for the teachers, evolution is or not goal-ended, determined or not by a project (the first meaning of chance defined above, in the introduction): 2 questions.
- To identify the degree of teachers' knowledge related to the biological processes of evolution (origin of new species: macro-evolution): 6 questions, including B42 (importance of chance: Figure 3) and B43 (importance of natural selection: Figure 4).
- To identify the teachers' knowledge related to elementary stochastic processes which are not directly related to evolution: "*When a couple has already had two girls, the chances that their third child be a boy are higher*" (question A31: Figure 5).

These questions are not related to all the possible meanings of "chance", as exposed above, but are focused on the degree of acceptance or reject of evolution and of chance in the evolutionary processes. The questionnaire is submitted in several contrasting countries to identify the link between these degrees of acceptance or reject and the socio-cultural context of each country.

Countries were chosen from their diversity: 13 were involved in the BIOHEAD-Citizen project, and 8 others are new (data obtained in 2009-2012): Australia, Brazil, Burkina Faso, Cameroon, Denmark, Georgia, Serbia, Sweden (Figure 2)

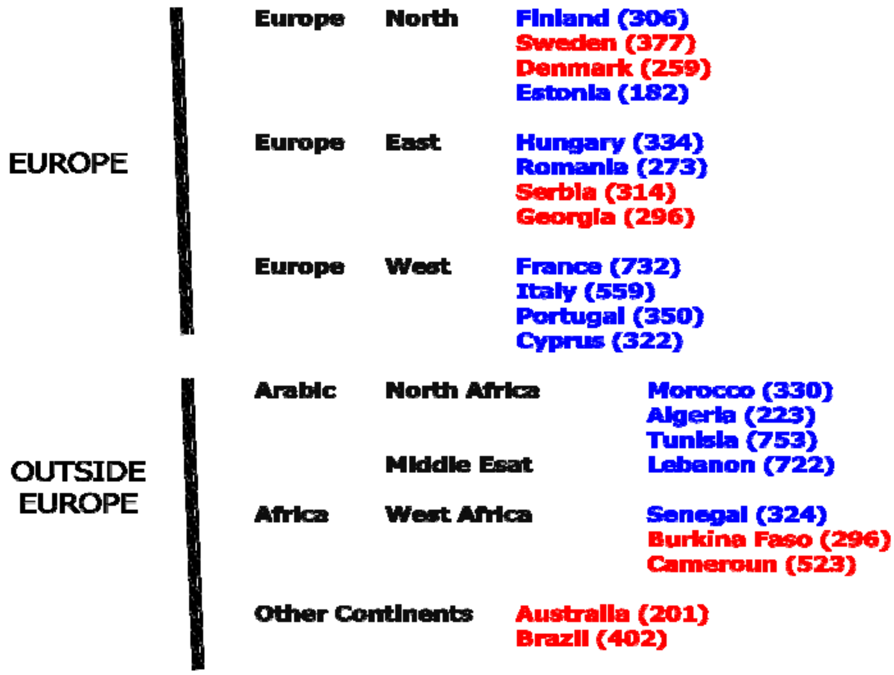

Figure 2. Sampling in the 21 countries: in blue are the countries involved in the Biohead-Citizen project (data collected in 2006-2008); the other countries are shown in red (data collected in 2009-2012).

Five other countries involved in the Biohead-Citizen project (Germany, U.K., Poland, Lithuania and Malta) are not included in the present work, because they decided to use a shorter version of the questionnaire, omitting the “part B”. Most of the teachers’ responses analyzed in the present work come from part B of the questionnaire.

After the end of the Biohead-Citizen project, the choice of new countries was done for specific reasons. For instance, concerning the countries outside Europe, we initially had only Muslim countries (North Africa, Senegal and Lebanon, including 1/3 of Lebanese teachers who were Christian). Subsequently, we decided to extend our sampling outside Europe to countries with a high proportion of Christian teachers (Burkina Faso and Cameroon in Africa; Australia and Brazil to start an expansion to other continents). In Europe, we chose two mainly Orthodox countries (Serbia and Georgia) and two new Scandinavian countries (with mainly Protestant or Atheist / Agnostic teachers: Denmark and Sweden).

Three categories of teachers answered the questionnaire in each country:

1/3 in Primary school,
1/3 in Secondary schools teaching Biology and
1/3 in Secondary schools teaching the national Language.

For each category, half are in-service teachers and the other half are pre-service teachers (the last year of training before teaching). The total number by country is indicated in Figure 1 (total = 8078).

The data are analyzed by classical statistical tests (such as Chi^2), but also by multivariate analyses using the "R" software (Munoz et al., 2007, 2009), but we will not include all the detailed results in the present work.

5. Findings

Figure 3 shows the responses of teachers to the question B42 related to the importance of chance in species evolution. For the following figures, we separated biology teachers (teaching biology in secondary school, but also some of the teachers in primary schools, when they were trained in biology at University) and other teachers (with no training in biology at University).

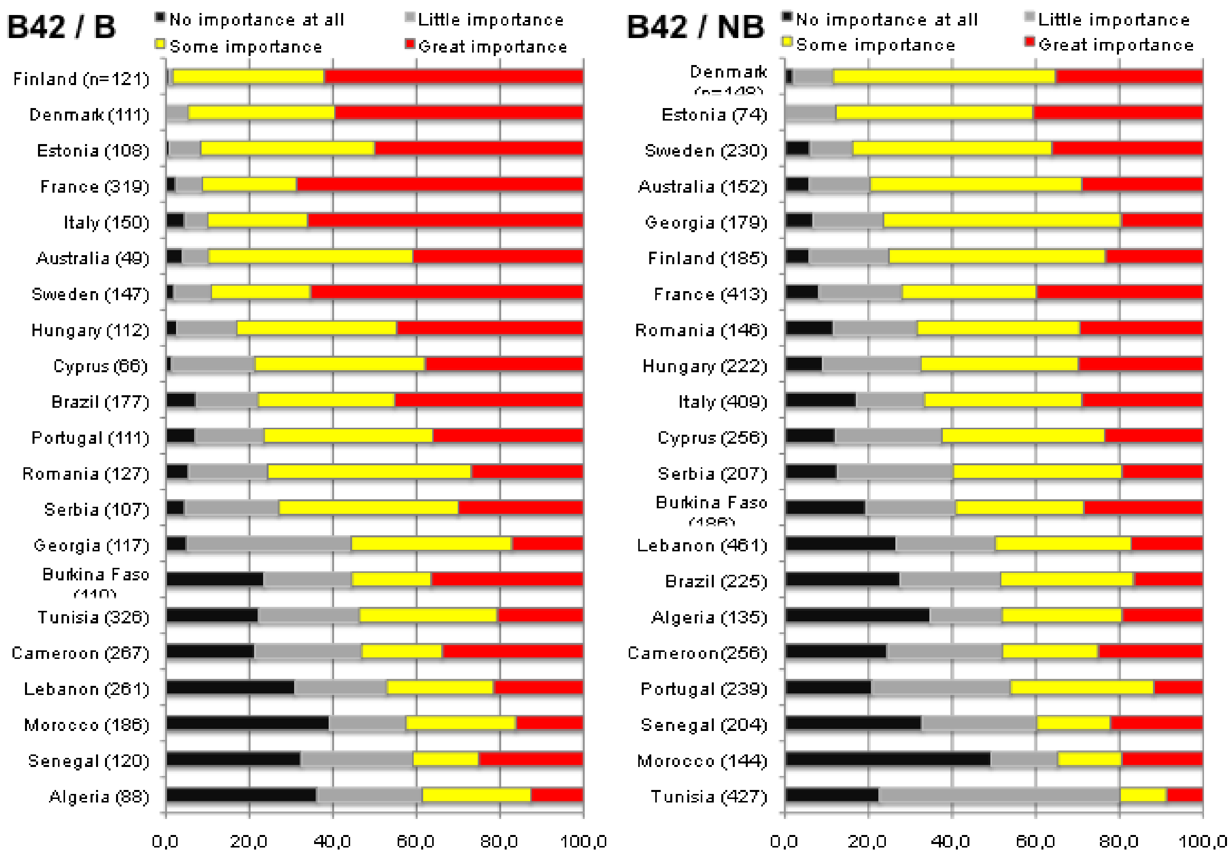

Figure 3. Biologist (B) and Non-Biologists (NB) Teachers' answers (grouped by country, N = 8078) to the question B42: *Importance of* ***Chance*** *in species Evolution*: (red) "Great importance"; (yellow) "Some importance"; (grey) "Little importance"; (black) "No importance at all".

The difference between biology teachers and non-biology teachers (Figure 3) is significant in 12 countries (Brazil, Cyprus, Denmark, Finland, France, Georgia, Hungary, Italy, Portugal, Serbia, Sweden, Tunisia), showing an effect of studying biology at University. Nevertheless, the percentage of biology teachers thinking that chance is not important in species evolution, remains high: between 61% and 40% in 8 countries (Georgia, Burkina Faso, Tunisia, Cameroon, Lebanon, Morocco, Senegal and Algeria), and >20% in 5 other countries (Cyprus, Brazil, Portugal, Romania and Serbia).

Are these high proportions linked to the topic evolution? We investigated this by looking at the responses related to the main Darwinian process: natural selection.

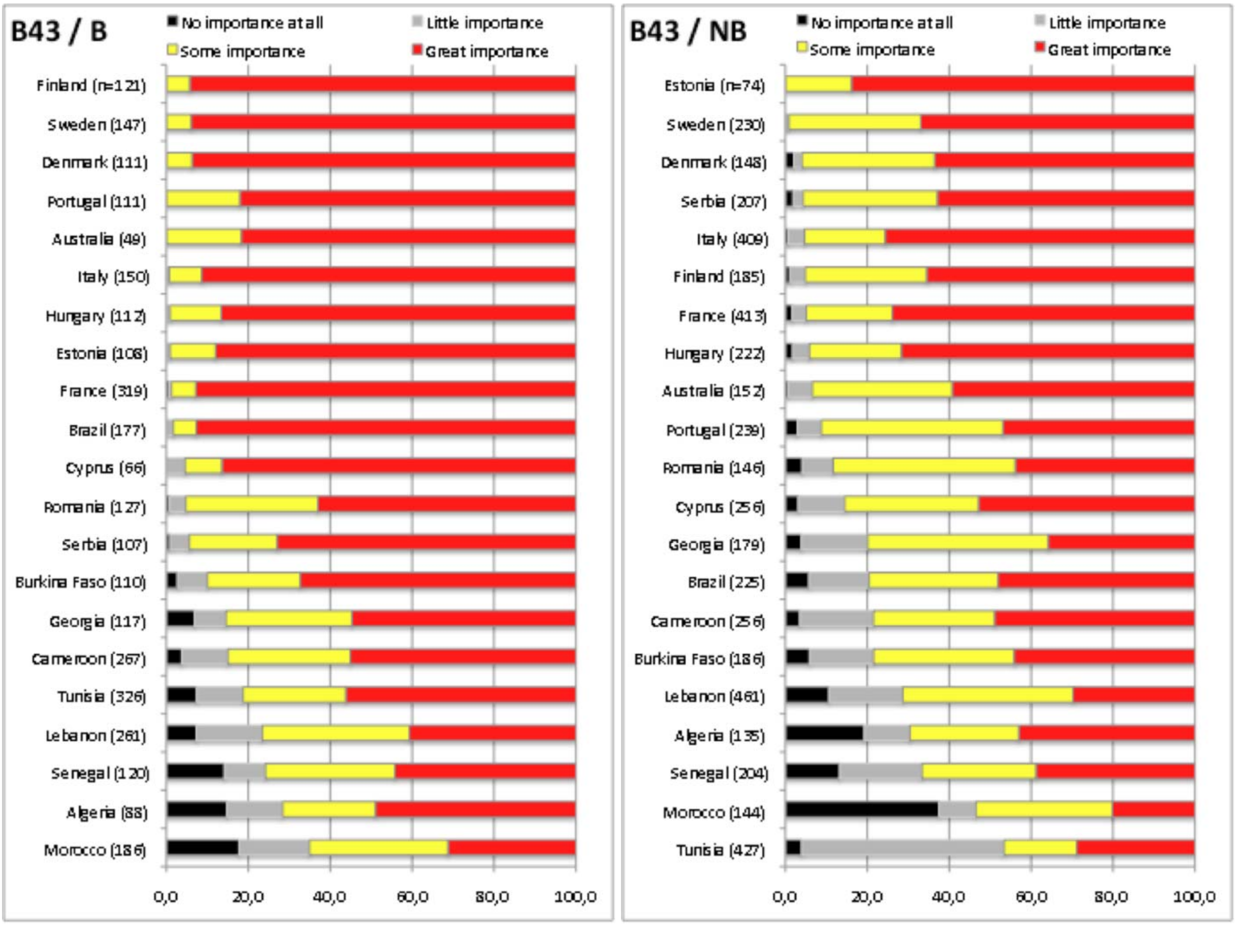

Figure 4. Biologist (B) and Non Biologists (NB) Teachers' answers (grouped by country, N = 8078) to the question B43: *Importance of* ***Natural Selection*** *in species Evolution*: (red) "Great importance"; (yellow) "Some importance"; (grey) "Little importance"; (black) "No importance at".

Figure 4 clearly shows that most of the teachers, in the 21 countries, ticked the boxes "great importance" of natural selection (red in the Figure) or "some importance" (yellow in the Figure): much more, in each country, than for the importance of chance.

Biologists are particularly convinced of this importance: only in the 5 African countries of our sample, as well as in Lebanon and in Georgia, between 10% (Burkina Faso) and 37% (Morocco) of biology teachers chose little or no importance of natural selection. In 13 countries, less than 5% ticked little or no importance, including 9 countries with 0%. In contrast, for the importance of chance, only in one country (Finland) less than 5% of biology teachers ticked no or little importance, and in 13 countries from 11% (Cyprus) to 61% (Algeria).

Non-biologist teachers are just a little less convinced of the importance of natural selection than their biologist colleagues: the difference between biologist and non-biologist teachers is significant (p<0.01; except Lebanon, p=0.02) in most of the countries, except in Cameroon, Senegal and Algeria (where evolution is not taught or of very few: Quessada et al., 2008; Quessada, 2008), and also in Estonia and Serbia where almost all the teachers know the importance of natural selection. Nevertheless, even for the non-biologist teachers, the percentages selecting no or little importance of natural selection are less than for chance: from 0% to 46% for natural selection (with 14 countries < 20%) while from 11% to 80% for chance (with only 3 countries < 20%).

These results show that (1) when trained in biology, as was the case for chance, more teachers know the importance of natural selection, even when having creationist conceptions (for comparison related to some of these countries, see our published results in Clément & Quessada, 2008, 2009, 2012 and below: Figures 6 & 7); and (2) teachers are more reluctant to accept the important role of chance than the important role of natural selection.

Is this last reluctance linked to the topic of evolution, or is it more general? We began to answer this question by analyzing our data related to a question where stochastic processes are not directly linked to evolution: A31 (Figure 5).

Figure 5. Biologist (B) and Non-Biologists (NB) Teachers' answers (grouped by country, N = 8078) to the question A31: ***When a couple has already had two girls, the chances that their third child be a boy are higher***: (red) "*I do not agree*"; (yellow) "I rather do not agree"; (grey) "I rather agree"; (black) "*I agree*".

Figure 5 shows that most of the teachers, happily, disagree or rather disagree with the proposition "*When a couple has already had two girls, the chances that their third child be a boy are higher":* from 79% (Georgia) to 97.2% (France) of biology teachers, and from 64.2% (Tunisia) to 94.4% (France) for their non-biologist colleagues. The difference between biology and non-biology teachers is significant in 13 countries, showing a better knowledge of stochastic processes after training in biology at University.

More importantly, these data show that the reluctance to accept the importance of chance is much more important when dealing with evolution (question B42, Figure 3) than when dealing with another process as in the proposition A31 (Figure 5):

- For biology teachers, in all the 21 countries, less than 21% did not agree with the role of chance for the question A31, while in 13 countries, 21% to 61.4% did not agree with the importance of chance in the evolution of species (question B42, Figure 3).

For the non-biology teachers, the disagreement with the importance of chance is between 5.6% (France) to 35.9% (Tunisia) when answering the question A31 (Figure 5), but from 10% (Denmark) to 80% (Tunisia) when answering the question B42 (importance of chance in species evolution: Figure 3).

In consequence, the difficulty teachers have in accepting the importance of chance in biological processes is more important when dealing with evolution. We can go further by analyzing the teachers' answers related to deterministic processes of evolution (Figure 6).

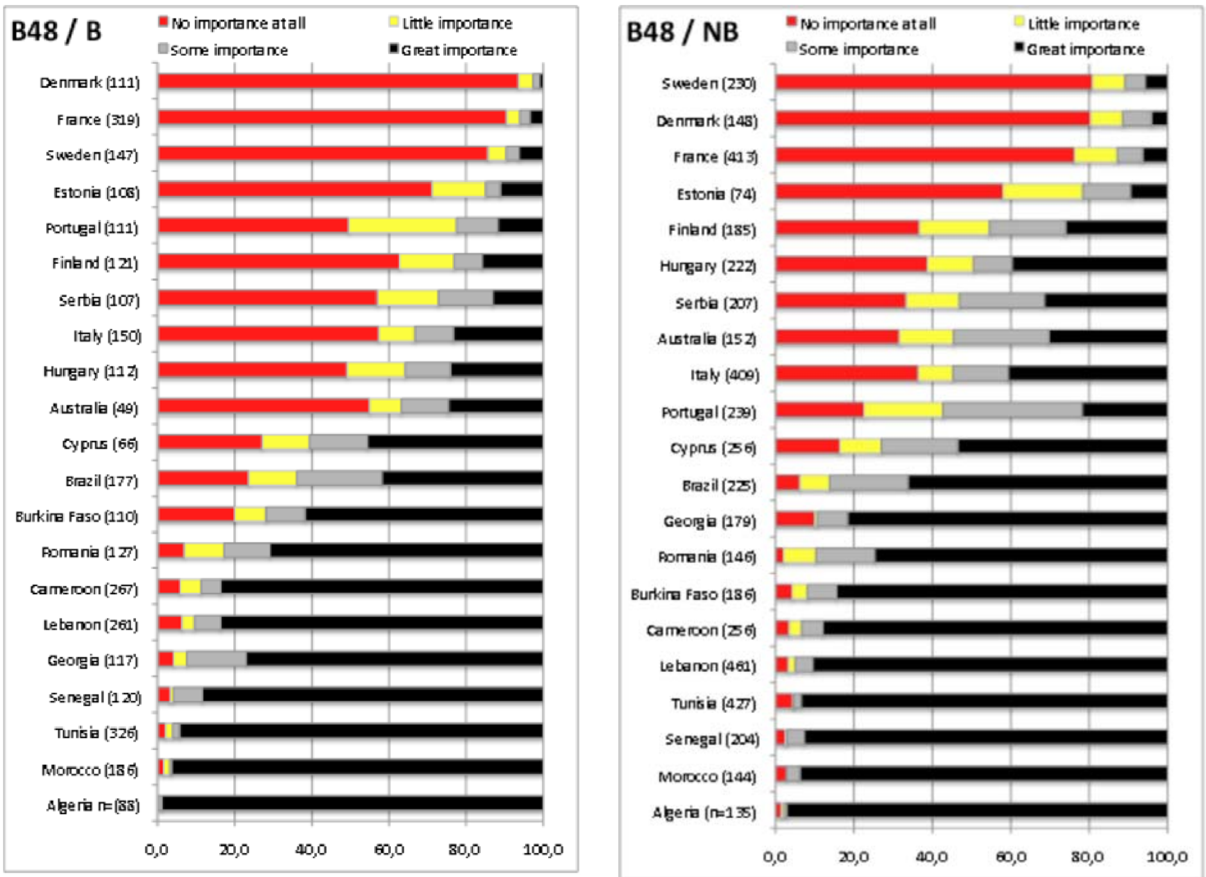

Figure 6. Biologist (B) and Non Biologists (NB) Teachers' answers (grouped by country, N = 8078) to the question B48: *Importance of **God** in species Evolution*: (black) "Great importance"; (grey) "Some importance"; (yellow) "Little importance"; (red) "Not important".

The teachers' answers to the question of the importance of God in species evolution (Figure 6) show more distinct differences among countries than the previous questions: for biology teachers: from 2.7% (Denmark) to 100% (Algeria) of great or some importance of God; as well as for their non-biologist colleagues: from 10.2% (Sweden) to 98% (Algeria). The difference between biology and non-biology teachers is significant in 8 countries (Burkina Faso, Brazil, Denmark, Finland, France, Italy, Portugal and Serbia).

Multivariate analyses show that there is a significant correlation between the answers to the question B48, Figure 6) and the level of practicing religion in each country (question P12b, Figure 7), whatever the religion is (Catholic, Protestant, Orthodox or Muslim), and with several questions related to evolution, as B28 (Figure 7).

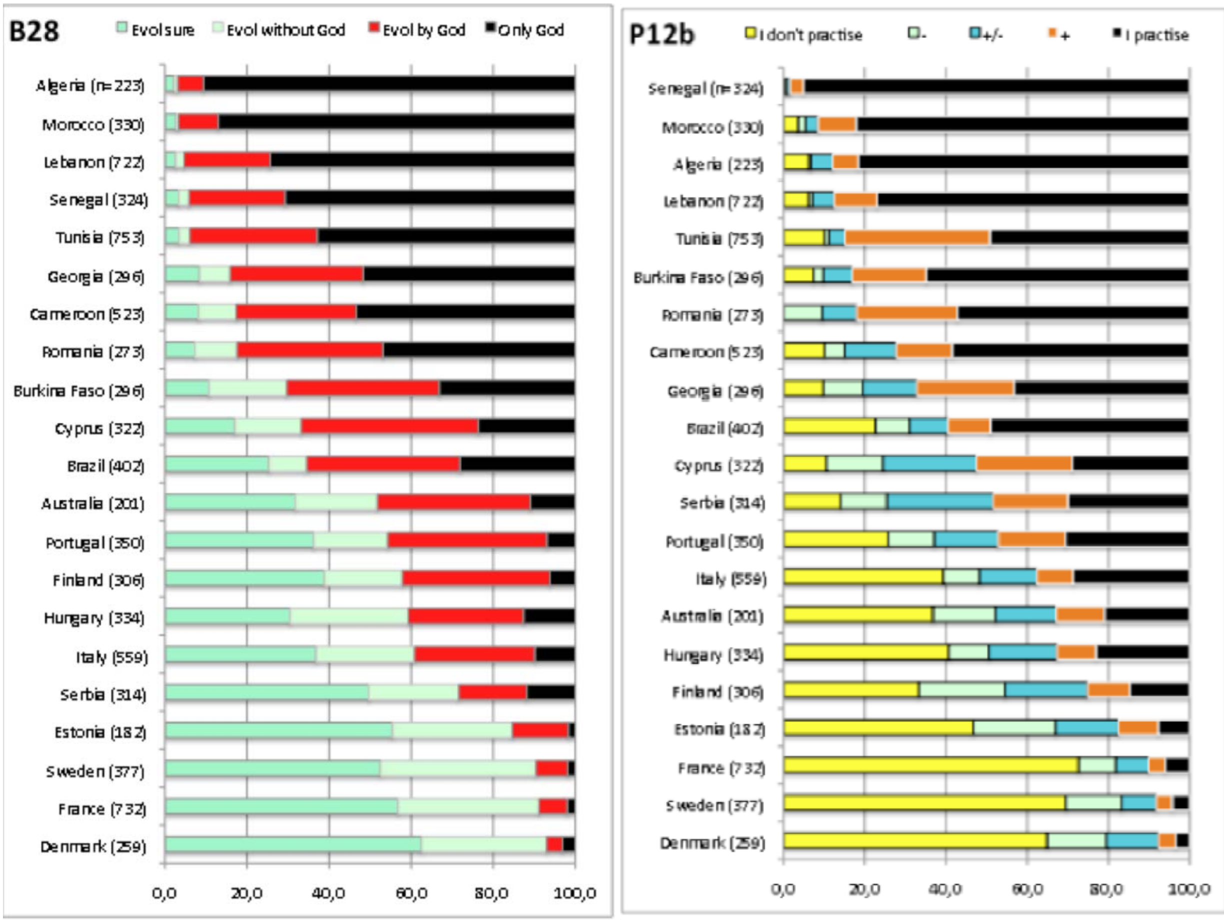

Figure 7. Teachers' answers to two questions of the questionnaire Biohead-Citizen.
N = 8078 teachers, grouped by countries (21 countries):
B28. Which of the following four statements do you agree with most? Select one sentence:

- ☐ It is certain that the origin of the humankind results from evolutionary processes.
- ☐ Human origin can be explained by evolutionary processes without considering the hypothesis that God created humankind.
- ☐ Human origin can be explained by evolutionary processes that are governed by God.
- ☐ It is certain that God created humankind

P12b: Five boxes between "**I practice religion**" to "**I do not practice religion**".

The comparison between Figures 6 and 7 shows that the teachers who practice a religion the most (P12b, Figure 7) also tick great or some importance for the importance of God in species evolution (B48, Figure 6) but select the item 3 or the item 4 to answer the question B28 on the origin of humankind (Figure 7).

While the item 4 is radically creationist "*It is certain that God created humankind*", the item 3 is at the same time creationist and evolutionist ("*Human origin can be explained by evolutionary processes that are governed by God*"). The well-known evolutionary biologist Dobzhansky expressed this kind of position in his famous paper (1973: *Nothing in Biology makes sense except in the light of Evolution*): "I *am* a *creationist and an evolutionist*. *Evolution is God's, or Nature's method of creation*" (p.127). This position is interesting in biology education, because it is not antievolutionist. More biology teachers than their non-biologist colleagues ticked this item, being believers and practising religion, but also evolutionist. In some countries, as in France and in Scandinavian countries, several teachers are simultaneously believers in God, practising religion and ticking the items 1 or 2 of the question B28, items that are clearly evolutionist.

6. Discussion and conclusions

Few studies have analyzed the perception of evolution at an international level. The largest and most known inquiry was published by Miller, Scott and Okamoto (2006) and compared the public acceptance of evolution in 34 countries, showing the minimum of acceptance in Turkey (25% of adults agreed with the proposition *"Human beings, as we know them, developed from earlier species of animals"*) and in US (40%). From a sociological study (Hassan, 2007) including only one question related to evolution *("Do you agree or disagree with Darwin's theory of evolution?")* Hameed (2008) published that 22% of Turks, 16% of Indonesians, 14% of Pakistanis, 11% of Malaysians and 8% of Egyptians agree, while 40% in Kazakhstan.

Working with teachers to analyze their problems and to suggest propositions to improve their training, the Biohead-Citizen research is also innovative for three other reasons:

- The quality of the questionnaire, with 14 questions related to Evolution, certain questions allowing the responder to say he / she is at the same time evolutionist and creationist, and also with several questions related to the four other topics of this project of research (genetic determinism, environmental, health and sex education), allowing correlations of responses to identify the teachers' systems of conceptions.
- The identity of samples in each country: the same categories and numbers of teachers; each teacher's personal information including his / her socio-political and religious opinions. In consequence, this allows rigorous comparisons and the identification of possible correlation between the teachers' conceptions of evolution and some of their personal characteristics.

- The diversity of countries: diversity of economical development, of geographical location, as well as of religion (depending the country, mainly Catholic, or Protestant, Orthodox, Muslim or also Agnostic / Atheist). Several of them were included for the first time in this kind of international comparison.

The large volume of the Biohead-Citizen data needs successive complementary analyses and publications. Some analyses related to evolution are further developed from a limited number of countries (12 to 19 countries: Quessada et al., 2007; Quessada, 2008; Quessada & Clément, 2011; Clément & Quessada, 2008, 2009, 2012) and we will publish soon a more complete presentation from 28 countries. The present work is the first to be focused in 21 countries on the analysis of teachers' conceptions on chance and determinism in evolution.

The correlation between the acceptance of creationism and the high degree of belief in God and practice of religion, illustrated here by the Figure 7, was already known from our first comparisons of 12 to 19 countries. It is not a surprise to find it again from 21 countries. This influence of religion on the revival of creationism is presented and discussed in several articles and books: among others, Jones and Reiss (2007), Coquidé and Tirard (2008), or Portier, Veuille and Willaime (2011). Less work paid attention to the teachers' difficulty: for instance in U.K. (Reiss, 2008), in Brazil (El-Hani & Sepulveda, 2010) or in Lebanon (BouJaoude et al., 2009). Some authors, as Mahner and Bunge's (1996), or Dawkins (2006), argue that a person has to opt between a religious or a scientific perspective. Several others, as Cobern (1996) consider possible that a religious person develops a scientifically compatible worldview. Dobzhansky (1973) already claimed the same (see above). El-Hani & Sepulveda (2010) investigated the degree of compatibility between the worldview of Protestant biology pre-service teachers and scientific ideas related to evolution.

The results presented here confirm that an important amount of teachers believing in God, practicing religion (Figure 7-P12b) and believing in the importance of God in species evolution (Figure 6) are also evolutionist (Figure 7-B28). A large majority of them, moreover, agree with the importance of natural selection for species evolution (Figure 4): even in Algeria, half of teachers answered "great importance" of natural selection in species evolution (Figure 4) while nearly all believe in God, practice religion (Figure 7b), answered "great importance" for God in species evolution (Figure 6), and more than 90% ticked the most radical creationist item for the origin of life and for the origin of humankind (Figure 7a), Nevertheless, only 10% of these Algerian teachers answered "great importance" for chance in species evolution.

In each country, comparing the Figures 3 and 4, less teachers ticked importance of chance than of natural selection in species evolution. Even in France, where almost teachers are evolutionist, 10% of biology teachers and 20% of non-biology teachers ticked no or few importance of chance.

The reluctance to accept the importance of chance is more important when dealing with evolution (Figure 3) than when dealing with the acceptance of a stochastic process as the sex of a child (Figure 5). There is indeed approximately the same ranking of countries in these two figures, but the amount of scientific error for the sex of a child is largely lower than for the role of chance in evolution, in each country.

Here is an illustration of the KVP model (Figure 1), the knowledge (K) of some teachers interacting with the values (V) and practices (P) of their religion. They accept a process by random, by chance, when it is related to the sex of their child, and not in contradiction with their religious beliefs. In contrast, several of them do not accept the importance of chance in evolution, because their religion claims that the fine adaptations of life cannot emerge from a “blind chance”, and consequently would necessarily be the result of God’s design. The trap of this alternative is analyzed by Clément (2002) in some Christian (Jehovah's Witnesses, 1985) as well as Muslim discourses (Keskas, 1996): the eventual role of chance in evolution is the main target of attacks, ignoring that the scientists never reduced evolution to chance, the emergence of new species becoming from the articulation between chance (stochastic processes of differentiation by mutations, genetic drift, …) and natural selection. In these texts, there is no attack against the notion of natural selection, that can explain its widely acceptance by teachers practicing religion.

Finally, to take into account the different meanings of conceptions presented in the Table 1, we can say that in a first time our work presents situated conceptions of teachers, related to each single question. In a second time, we analyze the convergence between these answers, showing that teachers’ conceptions are more or less evolutionist or creationist. We illustrated this convergence by some figures related to some questions, but all the answers to the five questions related to this topic are convergent, and also correlated with the answers to the questions related to a possible goal-ended evolution. In other words, there are two poles inside the teachers’ conceptions, the most evolutionist one disagreeing with a goal-ended evolution, and agreeing with the importance of chance in species evolution, and the most creationist one having the inverse positions. In a third time, we correlated these types of conceptions with the nationality, or with the degree of belief in God and of religious practice, showing that evolutionist as well as creationist conceptions can be defined as social representations. In a fourth time, not presented here but starting to be analyzed in another publication (Clément et al., 2012), we can correlate these social representations related to evolution with those related with another topic, as the genetic determinism of some socio-cultural human features (e.g. housekeeping by women), putting in evidence “*systems of conceptions*”. The most creationist conceptions are correlated with a strong belief in a biological determinism of these human features.

Last point, the comparison between biology teachers and their colleagues shows that, in half of the analyzed countries, training in biology increases the percentage of evolutionist conceptions and of acceptance of the importance of chance in evolution. We can conclude with the necessity of training more and better teachers. Nevertheless, it will be difficult to change the teachers’ conceptions, because they are not rooted only in out-dated or up-to-date knowledge, but also in their values and social practices.

Acknowledgements

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5 CHARACTERIZING THE TACIT RELATIONSHIPS BETWEEN BIOLOGY TEACHERS' CONTENT KNOWLEDGE (CK) AND OTHER PROFESSIONAL KNOWLEDGE COMPONENTS

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Abstract

Considerable effort has been made in the last three decades to construct a well-established conception of science teachers' professional knowledge. Both Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) are considered as critical professional development resources for science teachers. Recently, the interconnectedness between PCK and CK as an integral part of teachers' knowledge for practice has been raised. Exploring the relationships between CK and other professional knowledge components is not a straightforward process due to their internal tacit nature. In-service teachers who develop expertise in teaching possess tacit or intuitive knowledge which is difficult to reveal. The teachers who hold tacit knowledge about something will be unable to verbalize it and will often be unaware of it. Here we examine the possible relations between CK and other professional knowledge components of in-service biology teachers using the repertory grid technique which has been used to elicit experts' personal tacit knowledge. Data analysis revealed that CK is a very important component of teachers' knowledge and that it is by and large distinct from other professional knowledge components. We therefore believe professional development programs should strengthen the relationships between biology teachers' CK and other professional knowledge components instead of assuming that increasing CK will automatically lead to an improvement in teachers' professional knowledge.

Keywords: Pedagogical content knowledge; Content knowledge; Tacit knowledge; Personal Construct Psychology Theory; Repertory grid technique; Professional knowledge.

1. Introduction

1. 1 Teachers' knowledge base

Teachers hold a unique teaching knowledge known as PCK. Shulman (1986) was the first to suggest referring to teachers' knowledge as a special knowledge domain, divided it into three categories: (a) subject matter CK—the amount and organization of knowledge per se in the teacher's mind; (b) PCK—the dimension of subject matter for teaching, namely the ways of presenting and formulating the subject to make it comprehensible to others, and (c) curricular knowledge—the knowledge of alternative curriculum materials for a given subject or topic within a grade (Shulman, 1986).

The possible interconnectedness between the PCK and CK as an integral part of teachers' knowledge for practice is still controversial. Some researchers suggest that CK may enhance teachers' quality of teaching, while limited CK has been shown to be detrimental to PCK, limiting the scope of its development (Baumert et al., 2010). Moreover, it has been suggested that the degree of cognitive connectedness between CK and PCK among secondary mathematics teachers is a function of their degree of mathematical expertise (Krauss et al., 2008). In other words, it was suggested to be impossible to distinguish CK from PCK (Fernandez-Balboa & Stiehl, 1995; Marks, 1990). In contrast, other studies have indicated that science teachers' subject matter knowledge is not automatically transferred to classroom practice (Lederman & Gess-Newsome, 1992; Zeidler, 2002), implying that CK and PCK are different and distinct domains within the teacher's cognitive structures (Grossman, 1990; Magnusson et al., 1999; Shulman, 1986). Examining the relationships between PCK and CK is not a straightforward undertaking because expert teachers hold tacit knowledge about the role of PCK in their practice (Bjorklund, 2008) which is not easily revealed.

1.2 Tacit knowledge and the personal construct psychology theory

Tacit knowledge is often acquired through repeated experiences with a certain domain. The person who holds tacit knowledge about something will be unable to verbalize it and will often be unaware of it (Polanyi, 1966). Tacit knowledge is contextual and situated. As one repeatedly goes through certain experiences, one becomes an expert in that field. Experts are often unable to verbalize their 'know how' (Bjorklund, 2008), meaning that they know more than they can say (Polanyi, 1966).

Experienced teachers are usually able to function automatically. Many of their activities in class, such as their interactions with students, are behavioral patterns that they can invoke and perform without any conscious effort. Experienced teachers seem to have organized their knowledge of students and classrooms in particularly effective patterns that can be retrieved unconsciously from their long-term memory via classroom cues (Johansson & Kroksmark, 2004).

The inability to verbalize tacit knowledge and the fact that teachers may not even know that it is there controlling their decisions and actions, led us to search for a suitable method to elicit teachers' tacit non-verbal knowledge. Such a method was suggested by the American psychologist, George Kelly, who formulated the Personal Construct Psychology Theory (Kelly, 1955).

The Personal Construct Psychology Theory argues that people have different views of events in the world. These views are organized uniquely within each person's cognitive structure. Kelly (1955) established a psychological theory, the Personal Construct Psychology Theory, which argues that each person makes use of unique personal criteria, constructs to help him or her construe meaning from events. The Personal Construct Psychology Theory states that peoples' view of the objects and events with which they interact is made up of a collection of related similarity–difference dimensions, referred to as personal constructs (Kelly, 1955, 1969).

Following the formulation of the Personal Construct Psychology Theory, Kelly designed a method to elicit personal constructs, namely tacit knowledge, which is known as the repertory grid technique (RGT).

1.3 The Repertory Grid Technique (RGT)

The RGT is designed to elicit and probe personal tacit knowledge. It is a phenomenological approach which is more closely aligned with grounded theory and interpretive research than with positivist, hypothesis-proving, approaches. The technique appeals to the person's concurrent tacit knowledge on a given topic and encourages that person to confront his or her intuitions, to make the tacit explicit (Jankowicz, 2001). Detailed explanation of the technique used in this study is described in the Manual for the repertory grid technique (Jankowicz, 2004). Every grid of the RGT consists of four components: *topic, elements, constructs* and *ratings*. These components are usually elicited in a four-step procedure between an interviewer and an interviewee. The four steps are detailed below (see methodology). The RGT argues that this technique is free of external influences (Jankowicz, 2004). It overcomes the difficulties inherent in the collection of data with "traditional" instruments of investigation, in which interviewees are supposed to perceive and interpret the researcher's questions to match the researcher's meaning.

The main goal of this study was to discover the tacit dimensions of in-service biology teachers' PCK and its possible relationships with CK by means of a repertory grid. Two questions address the main goal:

1. What is the biology teachers' teaching knowledge repertoire?
2. What are the tacit relationships between biology teachers' CK and PCK?

2. Methodology

2.1 Research Context

The context of this study is a unique professional development program for outstanding high-school science teachers entitled the Rothschild-Weizmann Program for Excellence in Science Education, given at the Weizmann Institute of Science. The aim of this program is to provide a learning environment that may enrich the participating teachers' knowledge in both contemporary topics in science or mathematics and science education theories. The participants hold a Bachelor of Science (BSc) degree and are studying toward a Master's degree in science education without a thesis in the course of the program. The program's curriculum runs for eight hours a day, twice a week, over the course of four semesters. Each semester, the teachers participate in different science and science education courses.

The program includes a long-term "Designing New Teaching and Learning Materials" workshop, which served as the context for this research. The workshop is aimed at promoting the teachers' professional development through design activities. The workshop lasted three semesters and the product of this longitudinal course was the teachers' final projects of their Master's studies.

2.2 Research Population

The population of this study consisted of a total of 20 teachers participating in the above-described professional development program. The study's population included experienced in-service high-school biology teachers with 7-22 years of teaching experience from a variety of high schools: national (n = 11), religion-oriented (n = 7), boarding school (n = 1), and Bedouin (n = 1).

2.3 RGT

Tacit dimensions of PCK were analyzed according Kelly's Personal Construct Psychology Theory (Kelly, 1955) using the RGT. We followed the four above-described elicitation steps of the RGT at the termination of the professional development program. The four steps procedure takes about an hour and they are detailed in the following.

Step 1- Introducing the topic

Initially, we asked each group the same question: "What does a biology teacher need to know in order to be a good biology teacher?"

Step 2 – Choosing the elements

Each teacher was asked to write down, on 12 separate cards, the elements that a teacher should possess in order to be a good biology teacher.

Step 3 – Elicitation of personal constructs

Each teacher was asked to fold each element card so that he or she could not see what was written on it, place all 12 cards on the table and randomly pick three cards. After unfolding the three cards, each teacher was asked to write down the contained elements in a four-column table, each element in a separate column. Then the teacher was asked to choose the exceptional element of the three, circle it, and write down in the fourth column the reason that two of the elements were similar and the third exceptional. For example: Teacher A3 picked up the elements: 'ecology', 'the human body' and 'critical thinking'. She chose the element 'critical thinking' as an exceptional and wrote that the first two are content knowledge elements and the third describes a skill (see Figure 3). The teachers were then asked to refold the cards, return them to the table, mix them and then again randomly choose three cards. This action was repeated 10 times with each interviewee.

Step 4 – rating

At this stage repeating explanations for choosing the exceptional elements were defined as constructs. Each teacher was then asked to write down the opposite of a given construct, meaning that he or she had to define the construct poles, in a new empty table. On the right-hand side, the teacher was asked to write the definition of each construct and on the left-hand side, the opposite of the construct's definition. Each teacher was also asked to write the elements, each as a header of a separate column. Then each teacher was asked to rate the correlation between each element and each construct on a five-point scale in which '1' means 'totally agree with the left pole of the construct' and '5' means 'totally agree with the right pole of the construct'. The full tables constructed by each teacher were handed to the researcher for computed data analysis.

2.4 Content analysis

For content analysis of the repertory grid data, all of the interviewees' elements were pooled and categorized according to the meanings they expressed. The categories were derived bottom-up from the elements themselves, by identifying the various themes they expressed (Jankowicz, 2004).

2.5 Cluster analysis

Once the constructs were elicited and rated, the cluster analysis calculations (using factor analysis calculation) were performed with REPGRID, version 5software (http://gigi.cpsc.ucalgary.ca:2000/). This program provides a two-way cluster analysis grid in which there is the least variation between adjacent constructs and elements. The relationships between elements and constructs are visualized as tree diagrams arranging nearby the most similar rows and the most similar columns in the cluster. The tree diagram presents the elements at the bottom of the diagram (1, in Figure 3) and the coherence rate between the elements (the percentage of similarity between columns) at the top of the diagram using the coherence scale between elements which appears on the upper right side of the diagram (2, in Figure 3). The constructs are presented on the right and left (4, in Figure 3, opposite to each other), and their coherence rate (the percentage of similarity between lines) is presented on a scale on the right side of the diagram (5, in Figures 3).

Over 80% similarity is considered high coherence between the repertory grid's elements or constructs (Kelly, 1969). The meaning of the high coherence between elements or constructs allowed us to identify cognitive links between elements and between constructs, thus presenting an image of each teacher's personal mental model (Jankowicz, 2004). Subsequently, we searched for more than 80% coherence between CK elements and other professional knowledge elements, and more than 80% coherence between the CK constructs and other professional knowledge constructs, thus allowing us to identify the teachers' tacit knowledge about the relations between CK and teaching knowledge. Each teacher's data were analyzed individually and a repertory grid tree diagram (similar to the one presented in Figure 3) was drawn.

2.6 Validation of the RGT

We performed interviews for interpretive validity with five biology teachers. During each interview, the grid map of each teacher and our interpretations of it was presented to him or her. Each teacher was asked to express his or her view on the accuracy of the results referring themselves. The overall validation rate was 100%, meaning that each of the five teachers agreed with the RGT results and our interpretations. An additional validation of the outcomes was performed with another researcher that is familiar with the RGT. The overall validation rate was 95%.

3. Results

3.1 Biology teachers' teaching knowledge repertoire

Each teacher (n = 20) managed to elicit between 9 and 12 elements, for a total of 230 elements. 148 different elements, out of theses 230 elements, were different (mentioned by only one teacher), while the other 82 were repeated by 2 to 10 different teachers. For example: the element: 'knowing biology' was mentioned by 10 different teachers, while the element: ‘volume’ was mentioned by one teacher (teacher A3, see Figure 3). Thus, the teachers who participated in this study possessed a diverse repertoire of biology teaching elements. These elements were categorized according to their content. Six main groups of elements emerged in the course of the content analysis: (i) teaching skills; (ii) learning skills; (iii) relevance; (iv) CK; (v) teacher's personality; (vi) learner's personality.

A close examination of the data revealed that each teacher possesses a different repertoire of biology teaching knowledge elements within these categories. Elements of the CK category were mentioned by all of the teachers, whereas the other elements from the other categories were mentioned only by several teachers (Figure 1). Examining the diversity of the elicited elements revealed that the CK category included the most diverse elements among the six groups of elements (Figure 2). In addition, the CK category seemed to be the most frequently mentioned category (33% of all of the elements), meaning that one out of each three elements that were elicited by all of the teachers was a CK element. We then focused on analyzing the coherence rate between elements from the CK category and other elements, to better understand their significance to the high-school biology teachers' practice.

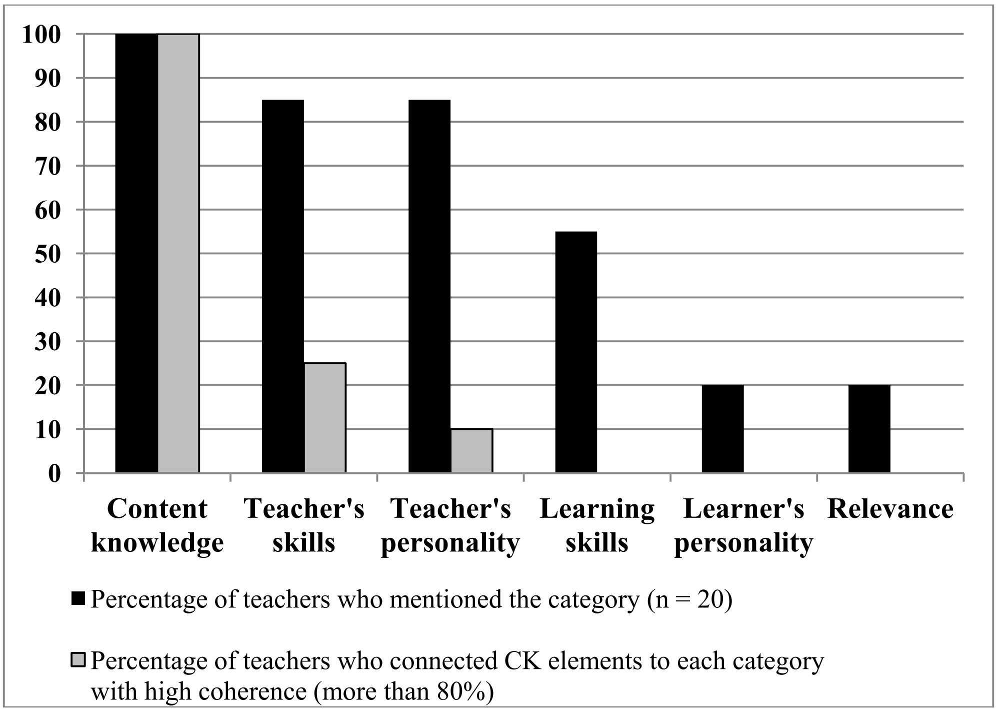

Figure 1. Percentage of teachers mentioning CK elements, and the percentage mentioning connections between CK elements and other elements.

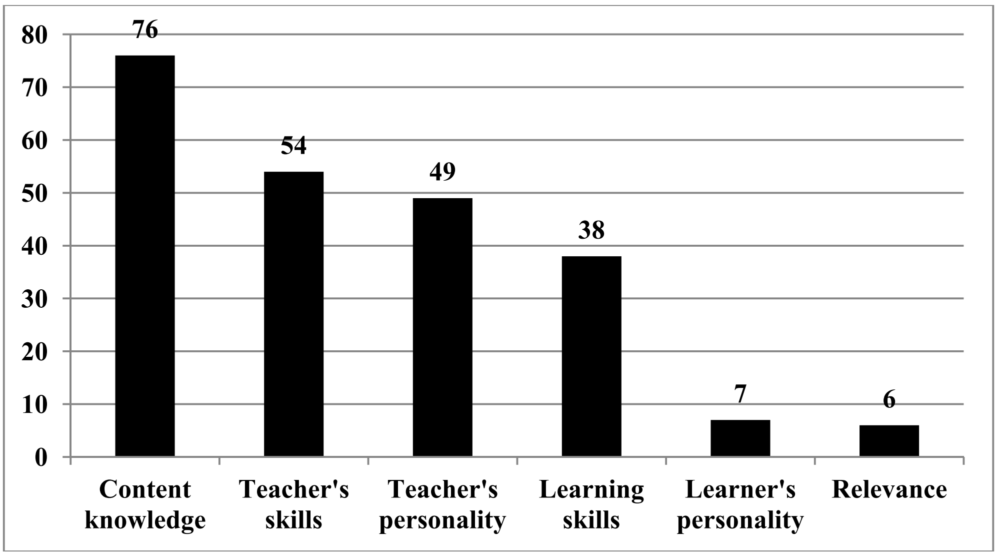

Figure 2. Diversity of elements of each category in the participating teachers' data.

3.2 Analysis of elements

Teacher A3's cluster is shown here as a case study (Figure 3). Twelve elements that were elicited by Teacher A3 during step 2 of the RGT are slanted at the bottom of the diagram (1, in Figure 3). The rate of similarity (in percentage) between the different elements appears at the top of the diagram on the element coherence rate scale (2, in Figure 3). Teacher A3's elements: 'The human body', 'volume', 'cell', and 'ecology' (3, in Figure 3) are similar with 85% coherence (2, in Figure 3). This means that these four elements constitute a group of elements that are considered similar by Teacher A3 with respect to biology teaching.

Analysis of each teacher's tree diagram revealed that all 20 teachers connected the CK elements with high coherence (Figure 1) namely, the CK elements appeared to be a separate group of elements. In addition, 35% of the teachers demonstrated high coherence between elements from the CK category and elements from the other categories. Five teachers (25%) connected elements of CK to elements of teaching skills (Figure 1) such as the ability to demonstrate biological knowledge, to characterize students' understanding and to teach in an experiential way. Two teachers (10%) connected CK elements to those of teacher's personality (Figure 1) such as enthusiasm for the wonders of nature, curiosity and openness to students' questions and ideas, and personal interest in science.

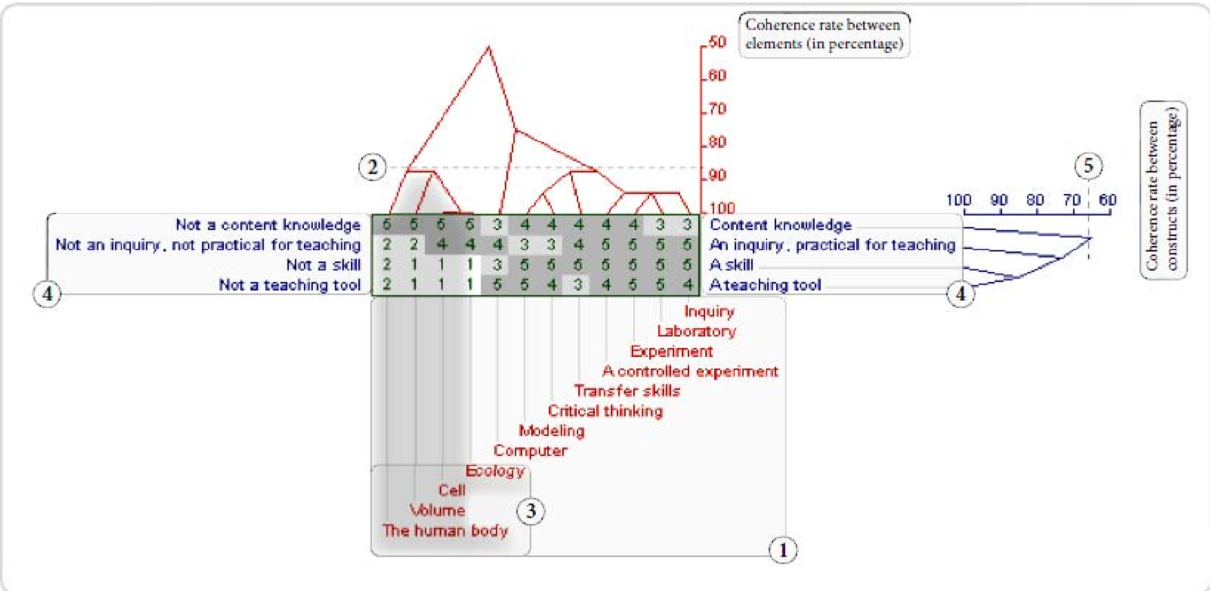

Figure 3. Analysis of Teacher A3's data using a repertory grid tree diagram (1) Elements; (2) coherence scale and its use in defining a group of elements (3) with more than 80% coherence; (4) constructs; (5) coherence scale and its use in defining coherence rate of the construct 'content knowledge' and other constructs (lower than 80% coherence).

3.3 Analysis of constructs

A similar analysis was performed for the constructs formed by the teachers. The constructs that were defined in step 4 of the RGT are listed opposite each other (4, in Figure 3). The coherence rates between the constructs (in percentages) appear on the right side of the diagram (5, in Figure 3). The graph on the right shows the similarity rates between the constructs corresponding to the graph. For example, the construct 'content knowledge' is 65% similar to the other constructs (5, in Figure 3). This means that 'content knowledge' is a different and separate construct within Teacher A3's cognitive structure regarding biology teaching, since less than 80% similarity was identified between this construct and the others (following Kelly, 1969).

Similar analyses of the RGT data collected from each of the 20 teachers revealed that 15 of them (75%) elicited the CK construct during step 3 of the RGT (not shown, see Figures 3 for examples). Fourteen out of fifteen clusters that included CK constructs demonstrated CK as a separate construct with a low coherence rate (less than 80%) with the other constructs (for example 5 in Figure 3).

Taken together, the analysis of the elements elicited by each of the participating teachers and the analysis of the constructs suggest that by and large CK is a unique category of biology teachers' knowledge which is not integrated as part of their professional knowledge.

4. Discussion

Investigating the interrelationships between various professional knowledge components may shed light on the nature of teaching professional knowledge and its role in teachers' practice (Park & Chen, 2012). Understanding biology teachers' knowledge about teaching may be an important factor in professional development programs aimed at enhancing teachers' professionalism (Henze et al., 2007). Here we examined the tacit dimensions of biology teachers' knowledge by means of RGT and showed that CK is not integrated as part of their PCK. This finding indicates that CK should not be considered an integral part of biology teachers' PCK, but can be considered a separate entity, as suggested by Shulman (1986, 1987).

A group of 20 high-school biology teachers were asked to intuitively elicit knowledge elements that refer to biology teaching practice. Intuitive elicitation of elements is important because the elements come from the teacher's cognitive structure with minimal impact from the researcher (Fransella et al., 2004). The elements of biology teachers' knowledge that were intuitively elicited in the course of this research raise three major issues: (i) knowledge is personal (following Kelly, 1955) in the sense of biology teaching. Appealing to the biology teachers' tacit knowledge, we found that 65% of the elements that were elicited by the teachers were unique (148 different elements out of a total of 230 elements). Each teacher who participated in this research thus possesses a unique repertoire of knowledge elements, and these elements are uniquely distributed among the element categories in each teacher's cognitive structure. This result may imply that biology teachers are a heterogeneous group with respect to their knowledge of biology teaching. This emphasizes the importance of considering diverse teaching perspectives during planning professional development programs (Rozenszajn & Yarden, 2011); (ii) knowledge is socially distributed (following Collins et al., 1989). Pooling together all of the elements that were elicited by the various teachers demonstrated the variety and large scope of knowledge within the area of biology teaching, thus emphasizing the importance of sharing knowledge between teachers during professional development programs; (iii) CK is an important factor of biology teachers' teaching knowledge. Of all of the elements that were elicited by the teachers, CK was the only element that all teachers mentioned. In addition, our analysis revealed that the CK category of elements was the most variable category of elements that was most frequently mentioned by the teachers. Although the cognitive structure of the teachers is variable, the relatively high frequency of elicitation of CK elements within all of the teachers' data suggests that CK is an important factor in these teachers' knowledge for practice (following Fernandez-Balboa & Stiehl, 1995; Marks, 1990), yet differs from other PCK components.

Analysis of the repertory grid data revealed that the biology teachers' CK was in most cases a different component of knowledge, distinct from other professional knowledge components. The coherence rate of CK elements with other elements was low, less than 80% on average. Seven teachers connected CK elements to elements that describe teaching skills, laboratory skills and learning skills. This might imply that although CK forms a different knowledge group in the RGT, there are teachers who consider CK an important part of their PCK. Therefore, these teachers hold a model of knowledge in which content and pedagogy are integrated and transformed into practice (Gess-Newsome, 1999; Krauss et al., 2008). It is possible that these teachers did integrate their CK with other professional knowledge components following their learning in academic biology courses and science education courses during the professional development program that they had participated in (Krauss et al., 2008), while the other teachers did not assimilate new CK into their existing professional knowledge. One possible explanation for the teachers not integrating CK with other professional knowledge components may lie in the fact that some teachers need to be encouraged to assimilate new CK into their existing knowledge. Another possible explanation may be that different teachers hold different teaching perspectives, some of which are not based on CK but rather on cognitive procedures (Rozenszajn & Yarden, 2011). This question remains open and is a subject for further research.

The analysis of CK constructs reinforced the conclusions of the analysis of CK elements. Teachers make sense of their practice through constructs regarding teaching. Seventy-five percent of the teachers who participated in this research used the CK constructs as an integral part of their cognitive structure about biology teaching, but the coherence of the CK constructs with other constructs was low. That is, CK is an important yet separate domain of knowledge in these teachers' cognitive structures. It is worth noting that all of the teachers who connected CK elements to teaching or learning strategy elements demonstrated a separate CK construct, except Teacher A2, who connected CK constructs with teaching and thinking skills constructs (data not shown). This teacher was unique since she views acquisition of biological content knowledge as a very important factor in her professional development and a very important factor in her teaching and her students' learning. However, characterizing this teacher's knowledge structure and the way she refers to CK as a part of PCK is a subject for future research.

We realize that although our results may imply that by and large the participating teachers do not connect CK to other professional knowledge dimensions, including PCK, it is possible to assume that the RGT fails to reveal some hidden links in the teachers' cognitive structure. Therefore, further research which will employ various methods and a bigger teachers' population should be conducted in order to answer the subject in question which subsequently may help design effective professional development programs.

As the main contribution of this research, the RGT clearly shows that CK is a separate domain in these biology teachers' cognitive structure regarding biology teaching. The theoretical frameworks related to professional knowledge usually exclude CK from PCK (Shulman, 1987). However, some practical studies of PCK within educational systems emphasize the importance of CK and include it as an integral construct of PCK (Fernandez-Balboa & Stiehl, 1995). The high coherence between the elicited CK elements and the separation of the CK constructs from the other constructs strengthen the notion that CK is indeed a very important, but separate domain of biology teachers' knowledge. Thus, professional development programs should promote the connection between biology teachers' CK and other professional knowledge components instead of assuming that increasing CK will automatically improve teachers' professional knowledge. Moreover, it is likely that even if teachers do link between CK and PCK to some degree in their practice it is important to bring to mind the ability to recognize this link and articulate it during professional development programs. Making the tacit link explicit may further promote teachers' professional development.

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SECTION 2

Biology education in informal settings

6 BEGINNING BIOLOGY– INTEREST AND INQUIRY IN THE EARLY YEARS

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Abstract

In a German botanic garden, Kindergarten children were presented opportunities for first hand observations of plants. The experiences were facilitated by educators from the venue who did not instruct but provided challenges and supported the children during their investigations. We wanted to find out if this approach facilitated the development of situational interest and whether theoretical categories postulated by researchers in interest theory (e.g. the need for competence) were identifiable in the responses of young children.

Data were collected using a multi-method approach. In this paper, we focus on data from participant observation of the children's behaviour and conversations. The data have been validated with data from post-visit interviews and questionnaires. Analysis was performed by reiterative reading of the completed observation sheets. Categories that emerged were matched with those that had been postulated in previous research.

The data indicate that the children's interest was caught and maintained. The novel situation, which consisted of being self-directed learners in an out-of-school environment responding to the opportunity for hands-on/minds-on experiences, engaged the children. Meaningful science challenges and the responsibilities given to children, maintained their interest. The theoretical categories postulated by researchers in interest theory were identifiable within the data from these children.

1. Introduction

Learning biology often starts with a child's first hand observations of the living world. A novel experience can catch the learners' interest and lead to further engagement with the environment and its contents (Dohn, 2011). Through urbanisation and a reduced freedom for children to play unsupervised, there has been a loss of opportunity for children to readily engage with natural objects and living things in their home environment – especially in big cities. Children in the developed world are increasingly referred to as being out of touch with nature (Louv, 2006). In order to develop an understanding of the natural world in such children, educators should seek ways to bring children into contact with more living organisms, animal and plant in particular. Opportunities for school children and children with their families/carers to encounter living things in their natural and human constructed environment such as gardens need to be planned. However, teachers' limited content knowledge in primary science (Harlen, 2001), including biology and biology teaching pedagogy, their low science teaching efficacy and the pressure to teach language, literacy and numeracy are probable reasons why early childhood teachers devote less time to plan such opportunities for living world encounters. One possible solution could be a stronger focus on programs organized in out-of-school/Kindergarten environments.

In such a program, provided free of charge in a German botanic garden, Kindergarten children (between 4 and 6 years of age) were presented opportunities for first hand observations of plants in greenhouses as well as open gardens and associated animals. The children were afforded time to first observe natural phenomena (Tomkins & Tunnicliffe, 2007) and to investigate them afterwards, assisted by adults, from both the school and the gardens.

Children, in groups of twelve, and their Kindergarten teachers, visited the garden for three successive days to explore basic botanical phenomena. The rationale was to develop the interest of children in plants through a variety of interactions, including cultural and inquiry-based activities. These included listening to fairy tales with plants as main actors, handicraft activities, an Asian tea ceremony and cooking. The learners were actively involved in inquiry (Harlen & Qualter, 2004), e.g. investigating plant growth. The accompanying teachers were expected to be learning partners and supportive facilitators, not instructors. The personnel from the botanical garden, a biologist/gardener and an educator, combined content knowledge and pedagogical skills, facilitated the experiences, provided challenges and supported the children inside the greenhouses and out in the gardens as appropriate to the task.

2. Theoretical background

As theoretical framework we used the Person-Object-Theory of Interest (Krapp, 1999; Schiefele, 1991) where interest represents a specific relationship between a person and an object (Figure 1).

An object of interest can refer to a concrete thing, for example a plant, as well as to a topic, a subject-matter, such as pollination, or an abstract idea, such as aesthetic properties of plants.

The realization of an interest requires an interaction between person and object – both concrete hands-on (e.g., child smelling flowers) as well as abstract cognitive working on a specific problem and to having ideas without conscious control (e.g., day-dreaming). If experiences during this interaction are positive, interest is likely to emerge in response to situational cues (= situational interest).

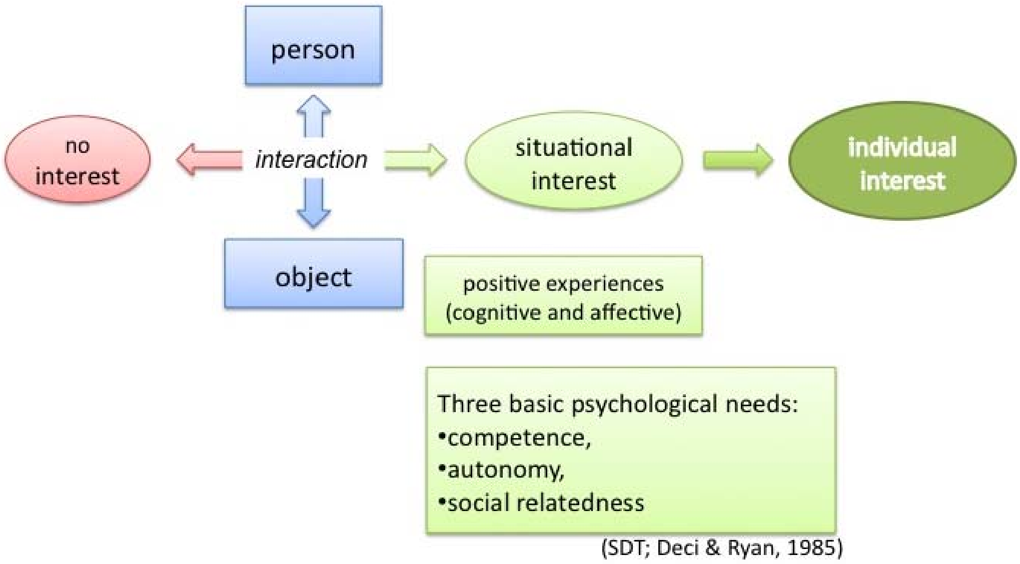

Figure1. Person-Object Theory of Interest (Krapp, 1999; Schiefele, 1991): Illustration of the main components.

Situational interest (SI) is captured by three factors (Linnenbrinck-Garcia et al., 2010) (Figure 2): The first, triggered situational interest, reflects the positive affective reaction learners can have to presentation of learning material. Triggered-SI, similar to the conceptualization of 'catch' (Mitchell, 1993), involves 'grabbing' a person's interest. In contrast, maintained situational interest, also referred to as 'hold', is a deeper situational interest form. Learners begin to build a meaningful connection between themselves and the object. Maintained-SI refers to reactions to the material itself, in this case biological specimens and phenomena. It consists of feeling-related components (maintained-SI-feeling), which characterize a person's affective experiences while engaging with the object (e.g. amazement), and value-related components (maintained-SI-value), which emerge as individuals come to believe the focus of such attention is meaningful. According to Krapp (2002), emotional feedback depends on whether or to which level the three basic psychological needs (Self-Determination Theory = SDT by Deci and Ryan, 1985) are satisfied, i.e. the need for competence, autonomy, and social relatedness. The need for *competence* is centered on skills, and the desire to feel effective in interacting with the environment. *Autonomy* refers to the degree to which behaviours are perceived to be caused by the self and to experience freedom versus being directed by others. Satisfaction of *relatedness* needs means one feels connected to others (e.g. to be a member of a group). Just as the fulfilment of basic biological needs (e.g. for food and water) is a natural necessity, sufficient fulfilment of the three psychological needs is a necessary requirement for optimal functioning of the psychological system (Deci & Ryan, 1985). With respect to interest development, the need-related qualities of experience are important because they provide positive emotional feedback and thus contribute to the emergence of object-related preferences. It is postulated that a person will only engage continuously in a certain area of tasks or topic-related objects if he or she assesses these engagements as meaningful and if the person experiences the interaction with the object as positive and emotionally satisfactory (Krapp, 2000).

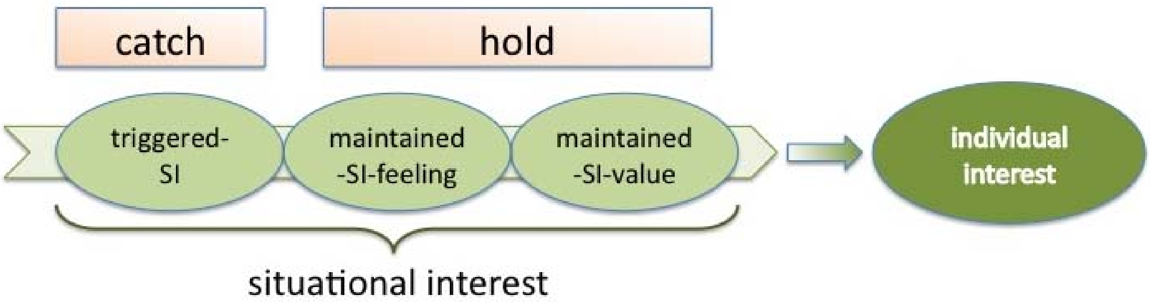

Figure 2. Three-factor structure of situational interest (Linnenbrick-Garcia et al., 2010; Mitchell, 1993).

Maintained-SI differs from triggered-SI because the enjoyment of engagement with the object is based in the domain rather than peripheral aspects e.g. learning material or environment. Maintained-SI provides the link between triggered-SI and individual interest, a more or less stable preference for a particular object. The interest relation to an object is characterised by cognitive and affective components (e.g. knowledge about the object and fun during person-object interaction). Other characteristics refer to the individual's values (e.g. readiness to spend both time and money).

3. Key objectives

We wanted to find out if the approach used during this program in the botanic garden facilitated the development of situational interest in these early years children. According to the theory, we postulated that the three basic psychological needs (for competence, autonomy and social relatedness, Deci and Ryan, 1985) have a critical influence on the development of situational interest: we argue that if the children feel competent and can choose from different activities as well as experiencing supportive relationships with teachers, other adults involved and other children, situational interest will be triggered. Through collecting appropriate data from the different groups involved in the activities, we sought to ascertain if these theoretical categories (*basic needs*) were identifiable in the responses of individual young children and hence verify the theory.

4. Research design and methodology

Data were collected from different perspectives using several different instruments. In this paper, we focus on the children's perspective. This perspective was obtained through a multi-method approach (*triangulation,* Cohen et al., 2007, Figure 3) to enhance confidence in the ensuing findings: The first research approach – participant observation – was that the researcher observed the children's behaviour during the entire program using a predesigned observation schedule (Figure 4) and recording and transcribing the children's conversations. Appropriate permissions were obtained. The goal was to find out which specific factors support the development of interest (e.g. What catches the children's attention? Which activities do the children choose, concentrate on and stay with for a longer time?). A special focus was on the children's reaction to different kind of activities and to the level of support by the accompanying adults (e.g. more guided or more open). The second research approach was the obtaining of the opinion of the children themselves through post-visit individual interviews. These interviews took place 2-4 days after the program, back in the Kindergarten. Children were asked what they liked most and why. Photographs, which had been taken during the program, were shown to the children to encourage them talk about their individual experiences. If specific behaviour had been noticed during the program, children were asked for explanations (e.g. 'I have noticed that you…'). Responses were tape-recorded and transcribed afterwards.

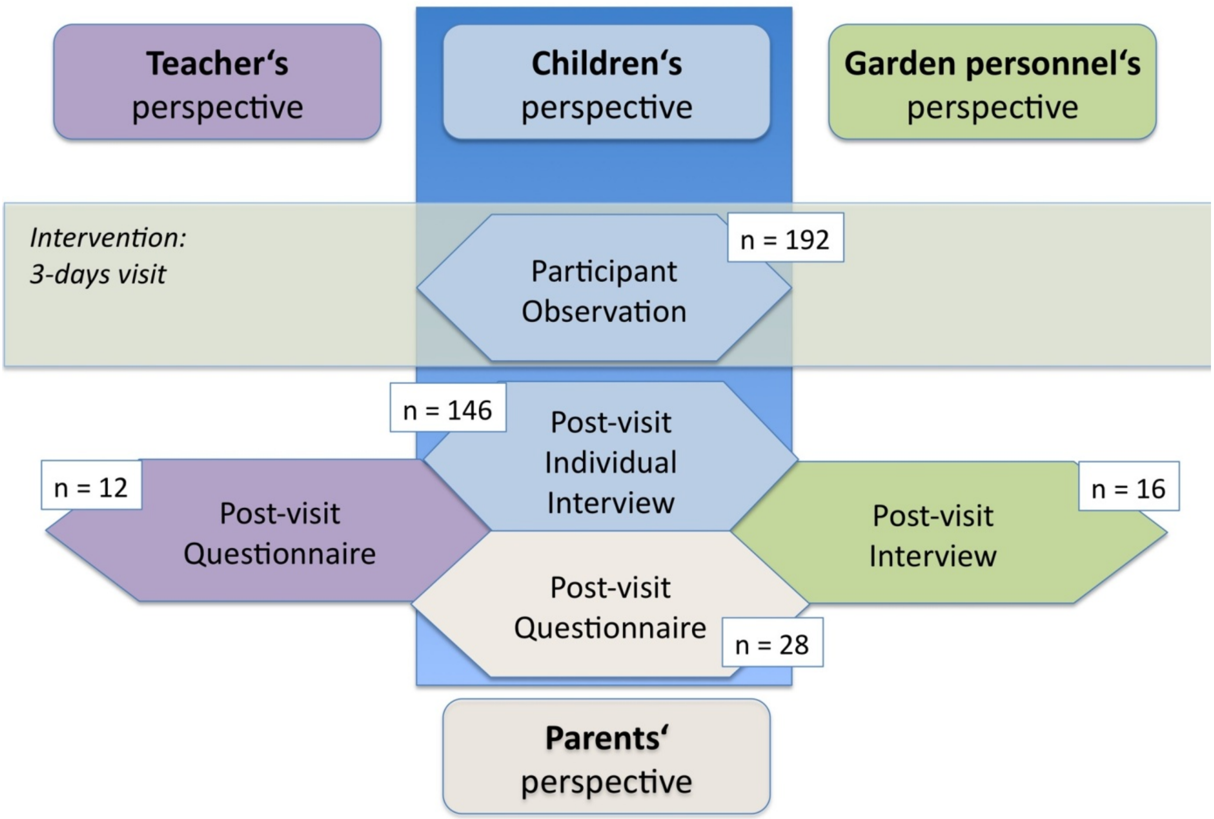

Figure 3. Multi-method approach to capture the children's perspective.

The third research approach was the accompanying teachers reflecting on their children's responses in post-visit questionnaires (open and closed questions). They were for example asked to characterize the group of children (e.g. cultural background), if they had noticed unusual or unexpected behaviour or if their children seemed to be either bored or overloaded (being signs for lack of feeling of competence). These questionnaires were handed out after the program. The teachers were asked to fill them out at home or back in the kindergarten and send them back afterwards. Fourthly, the garden's personnel were asked in post-visit interviews about special incidents that may have occurred during the intervention to be able to relate this information to special behaviour of the children that may have been noticed by the observer. Lastly, the children's parents were asked about their children's conversations and behaviour concerning the program at home, using a short questionnaire with closed questions. This questionnaire was given to the parents during a special one-day family program in the botanical garden which took place some weeks after the main program.

Date: Observer:
Group (Kindergarten name, No. of children/adults):
Group characteristics (age, cultural background…):

Time	Responsible person (adult)	Part of the program/ Program phase	Media use	Activities/ Course of action	Observed behaviour, striking incidents	Interpretation, possible explanation

Figure 4. Observation sheet used to capture the children's behaviour during their visits to the botanical garden (Participant observation).

Sixteen groups, each of twelve children (N = 192), were observed during all of their three-day visit (48 days altogether). Observational data were validated with data from individual post-visit with the children (N = 146) and from questionnaire responses of the accompanying teachers (post-visit, N = 12) as well as the parents (post-visit, N = 28).

The categories that emerged from qualitative analysis, performed by reiterative reading of the completed observation sheets and dialogue transcripts were matched with those that had been postulated from the previous research. These categories can be grouped according to their function: a first group of categories helps to explain why interest develops or not; they refer to the *basic needs* (for competence, autonomy and social relatedness, see above). A second group of categories helps to detect developing interest relations; according to the theory, interest relations are characterised by cognitive, affective and value components (see above); the more a person knows or requires to know about a certain object of interest, the more positive emotional feedback he or she experiences during the engagement with the object and the more the person values this engagement, the higher developed is the interest relation. The observation of a child being unable to cope with a certain task is for example categorized as lack of competence and will be used to explain why interest development was probably hindered in this situation. The observation of a child being eager for knowledge, having fun and spending a lot of time doing a certain task is interpreted as beginning or existing interest relation (maintained situation interest, see above). During the individual interviews, children were asked about their specific behaviours to prevent false interpretations. In addition, the teachers and parents responses from the questionnaires were used to provide even more robust results.

5. Findings

According to the theory, we postulated that the three basic psychological needs (for competence, autonomy and social relatedness) have a critical influence on the development of situational interest. We argued that if the children feel competent, and can choose from different activities as well as experiencing supportive relationships with teachers, other adults involved and other children, situational interest will be triggered.

5.1 Signs of situational interest

The data that we collected indicate that the children's situational interest was caught and maintained:

a) Knowledge gain (*cognitive component of interest*): The children in the project were able to apply knowledge which was highlighted or acquired during the tasks and interactions in the gardens. This claim is evidenced by the conversations of the children in the botanical garden's greenhouses where they recognized the different plants they had learned about before. The children, through their observations, noticed differences and were able to name the specific characteristics e.g. bamboo with its thin, pointed leaves and 'nodes' on the stems. These characteristics were mentioned by them in the post-visit interviews as well. The teachers noticed the children's increased interest and were surprised by their receptiveness ('Some children were more curious – both during the program and afterwards they asked more questions than they normally do.'; 'I was positively surprised by the enormous receptiveness of the children during these long program days.' - answers from post-visit teacher interviews).
b) *Affective component of interest*: The children enjoyed working during the different activities (laughing, use of expressions like 'wow' and 'cool') and remarked in the interviews that they had fun working on the activities requested in the program. This was also mentioned by the teachers in the post-visit interviews who have noted the children's excitement (e.g. 'All of them were full of enthusiasm.').

c) *Value component of interest*: The children respected the plants and valued specimens by investigating and taking them home. For example, they collected plant parts during their visits of the gardens and observed them closely with aid of magnifiers or microscopes when back in the educational area. Some of them also started small collections in shoe boxes which they took home to keep the things which they had collected and to show them to their parents.

Moreover, the teachers reported that they were astonished at the dedication of the children to tasks (e.g. 'No child was bothered by the trips through the Gardens, long ways to walk, putting on and off their clothes.').

5.2 Favourite activities

According to the observational data as well as the post-visit interviews with the children, favourite activities were those where the children fulfilled new and meaningful tasks with hands-on involvement (e.g. preparing the meal – some of them had never before helped in the kitchen – and planting a small plant to take at home afterwards). They also enjoyed 'playing' very much – activities which were self-directed and not determined by the teachers. These results are in accordance with the data from the parents' questionnaire (e.g. 'Did your child at home talk about the plant program?' Figure 5).

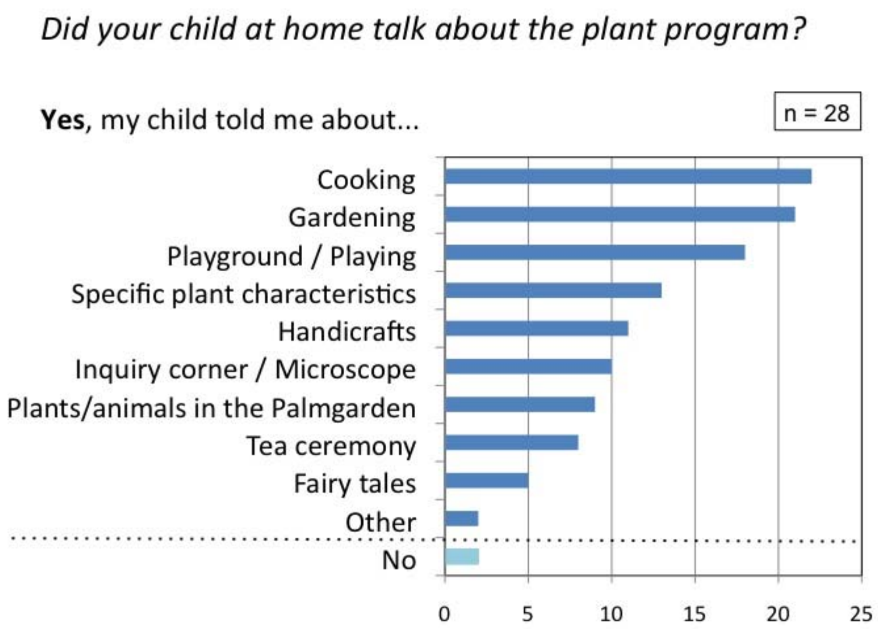

Figure 5. Activities that were mentioned by the children after the program at home.

5.3 Reasons for the development of situational interest

To explain why interest develops or not, these favourite activities were analysed more closely in relation to the theoretical categories postulated by researchers in interest theory (basic needs). Indeed, these were identifiable within the data from these young children:

a) The *need for competence* is reflected by the children's different reactions to certain tasks: As soon as they were either working below their capacities or on the other hand were unable to cope, their attention became less and the children showed signs of boredom or confusion (e.g. during a situation when the teacher explained where and how far Asia was, using a map of the world, it was observed that the children did not listen and started to do other things). In contrast, when children achieved in tasks they showed they were happy and proud (e.g. while serving the meal which they had prepared). This is also true for situations where the children could demonstrate what they had learned before: During the visits to the garden's greenhouses for example, the children were asked to find certain plants. Full of enthusiasm, they ran along the paths, trying to find as many plants as possible. They were proud to be able to find them and explained to the teacher why they had recognized them.

   During certain activities, opportunities were provided to the children to adopt special roles; the children enjoyed it very much being responsible for a certain task and took these tasks very seriously. As 'official photographer' for example, the children had to handle a digital camera and to take pictures of certain plants or situations (e.g. during the trips through the gardens). These pictures were printed by the garden personnel the same day and used afterwards during the program to reflect together with the children on selected contents. The observational data reveals that the 'photographer' was especially proud having competently fulfilled his task. This is in accordance with the data from children's post-visit interviews where these children proudly point on their photographs, emphasising that they (!) had taken them.

b) The *need for autonomy* can be detected in the data in respect to the amount of self-directed learning and the children's reaction to it: Most of the activities in this program allowed the children to be autonomous and self-directed learners. This opportunity was used by the children to explore and to discover. They enjoyed being allowed to choose freely what to investigate and how to approach, and stayed with certain activities very long (e.g. using the microscope to investigate small objects which they had chosen before by themselves). During inquiry-based activities, the Garden personnel were open to the children's questions and gave them a feeling of being 'research partners': they encouraged the children to observe plant characteristics, formulate hypotheses and to investigate them, acting as role model but without instructing.

   The children stated in the interviews that they enjoyed 'playing' – undirected, self-determined activities – very much. In contrast, activities or phases where the Garden personnel took lead for a longer time, and the children were passive and supposed to listen, their attention was comparatively low. This was also mentioned by the teachers in the post-visit interviews (e.g. -'Some children were less attentive than I expected during 'learning sequences' where the children sat down on a carpet and the Garden personnel talked/explained things.'). However, one activity of this kind was an exception: During an Asian tea ceremony, the children were supposed to sit and wait for about 5 minutes, watching the Garden personnel preparing the tea (ceremony with background music and special equipment). In this case, the children were very attentive and observed the preparations. Even the teachers were astonished about the children's reaction (e.g. 'I was positively surprised about the children's acceptance of the tea ceremony'; answer from post-visit teacher's interview). This fact might be explained in two different ways: For some children this type of ceremony was completely new and fascinating (novelty and surprise can play an important role in the development of situational interest; e.g. Dohn, 2011), for other children with Asian background this ceremony was known from home and could have caused a feeling of social relatedness. In both cases, the children had positive feelings about the situation/activity which was confirmed also during the post-visit children's interviews (e.g. 'The tea was nice and I liked the music with it').

c) The *need for social relatedness* appears to be very important to children at this age and therefore has influence on their interest development as well: The children in the program cooperated both with peers, their adult learning partners and the garden personnel. They discovered things together and asked for assistance during more difficult tasks from peers and adult facilitators, thus experiencing 'scaffolding' from a 'significant other', as postulated by Vygotsky (1962), in construction of further understanding of – in this case – natural phenomena. To have 'the expert' (Garden personnel) working with them was acknowledged by the children, and the teachers stood back to support this special relationship ('The possibility to discover and work with a microscope, scaffolded by the biologist (dialogue), offered new kind of experiences to the children.'; answer from teacher's post-visit interview).

   It was important to the children to exchange their ideas and discoveries with others and to find out about their opinion (e.g. asking the adult to have a look at the objects which they had found in the gardens) – if the others did not react immediately, the children insisted and sometimes even addressed several people.

The teachers noted more cooperation and less aggression than in the normal classroom (answers given in the post-visit questionnaires):

-'I noticed less conflicts between the children'.
-'I was very surprised by the group behaviour/positive interaction/cooperation.'
-'The children complained less.'

In addition, results show that this kind of program also meets the needs of immigrant children. The strong focus on hands-on activities and visualization as well as the integration of cultural phenomena seems to help the children to overcome language barriers and restraint/timidity.

Furthermore, the program had a very positive influence on the self-confidence of the Kindergarten teachers: as Harlen (2001) pointed out, many teachers of primary science are unconfident about their own subject knowledge. This is even more true for Kindergarten teachers. Working in partnership with personnel form the gardens assisted them in furthering their own scientific understanding. They stated in the post-visit questionnaires that they had learned a lot – both biological as well as pedagogical content knowledge.

6. Conclusion

The study shows that adults have a crucial role in facilitating the site and assisting the children in developing their interest and ideas. Meaningful challenges in a relevant and/or novel context (also cultural) offer an effective means to develop early inquiry-based science.

In out-of-school contexts, accompanying adults, if they do not instruct but offer to the children different activities to choose from and act as supportive partners in a co-constructive learning, encourage and enable such learning. The plants and the setting communicated a message to the young children who had their interpretative and educational experience enhanced by a significant someone, an adult facilitator or peer, enabling them to construct a further conceptual understanding.

Using a number of different approaches to establish the responses of early learners in novel biological tasks and an out of school location specifically designed for the study of biological phenomena provides a rounded view of such responses. Not only did we observe the spontaneous responses of the learner, we elicited their cued reactions through our questions to the tasks which were designed for them to be participants. Furthermore, we sought the views oft the three categories of adults involved in the project, the teachers of the children, the personnel of the botanic garden involved with facilitating the experiences of the children and indeed the parents of the participating children for their estimation of the response of their children to this program.

The data shows that the approach used during this program facilitated the development of situational interest in these early years children and that the three basic psychological needs have a critical influence on this development.

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SECTION 3

Models and modeling

7 STUDENTS' VERSUS SCIENTISTS' CONCEPTIONS OF MODELS AND MODELLING

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Abstract

In science models are important thinking tools, which are used to generate explanations and predications (Justi & Gilbert, 2002). Also in science education the importance of models and modelling is increasing, because there is an obvious focus on scientific literacy and inquiry based learning. However various studies identified that students have a simple understanding of scientific models, which is less elaborated than the scientific conceptions (Grosslight et al., 1991). In an effort to qualify and theorize these two perspectives, we adopted a qualitative approach to study how students and scientists conceptualize models and modelling.

To research the quality of students' conceptions, we collected data on German students' (grade 10 to 13) relevant concepts of models and modelling in semi-structured interviews. Simultaneously, we assembled established scientific conceptions from academic literature. We then employ the approach of educational reconstruction to align the scientific conceptions with students' conceptions of models and modelling aim at developing appropriate intervention guidelines (Kattmann et al., 1997). Our findings suggest that students perceive models as teaching aids for visualization and explanation; models are recognized to serve for visualization and explanation in scientific contexts too. However, unlike students, scientists conceptualize models as mediators or tools for generating new insights.

1. Introduction and research objective

"All insight is insight in models or via models" (Stachowiak, 1973, p. 56). This quote expresses the important role of models in science and science education. Harrison and Treagust (2000) even conclude that without models, science is neither teachable nor learnable.

However, various studies showed that students have a limited perception of models as depicting miniatures of real-life objects instead of instruments of an epistemological process and that their conceptualizations differ from those of scientists (Grosslight et al., 1991; Treagust et al., 2002). One reason could be that in the teaching and learning context, the descriptive aspect of models is predominantly perceived, whereas the models' heuristic function as thinking and working tools is not recognized. Thus, their role in formulating and testing hypotheses or theories does not seem to be sufficiently developed in school contexts.

This potential shortcoming is especially relevant in science subjects, where models are the major learning and teaching tools (Harrison & Treagust, 2000). Biology classes employ abstract and material models that are all based on mental models (Justi & Gilbert, 2002). Thinking in models enables communication and formation of consensus in science. Therefore, models and modelling are essential for the acquisition of flexible, transferable, and applicable knowledge (Clement, 2000; Gilbert & Boulter, 2000).

The sensible utilisation of models functions as a "door-opener" for a higher understanding of the nature of science because it leads to advanced levels of scientific thinking and working (Leisner, 2005). Model competence, that means the knowing about models and modelling and its application by using and building models (Upmeier zu Belzen & Krüger 2010) is therefore a profound part of scientific literacy (Gilbert & Boulter, 2000; Driver et al., 1996).

Based on this theoretical framework, this paper presents a qualitative survey of German students' (age 16 to 20/grade 10-13) relevant concepts of models and modelling and aligns these findings with scientific concepts of models and modelling as conceptualized in epistemological literature (Stachowiak, 1973; Mahr, 2008). Three components are put into relation with each other to create more effective lessons: students' conceptions, the scientific view, and the didactic structuring (Kattmann et al., 1997).

The survey is embedded in a larger research programme, which includes the design and testing of quantitative instruments in order to assess, support, and evaluate model competence and intervention strategies based on the theoretically founded structure of model competence (Upmeier zu Belzen & Krüger, 2010). Our research aims at deriving teaching guidelines.

2. Theoretical background

The theories which are used as a basis for the research design of our study draw from two fields of theories. The first concerns the required concepts for the survey, i.e. models and modelling. The second theory domain comprises relevant learning theories.

2.1 Models and modelling

Mittelstraß (2004) suggests that a model is a concrete depiction (because of reduction on the main focus). This depiction of abstract or confusing things or circumstances is then easier to understand or easier to realise. Models are used to describe and explain other systems (i.e. originals) or to make predictions about them (Hesse, 1970). Stachowiak (1973) defines that a model is a system, which is built as a purposeful and abstract depiction of another system. We refrain at this point, from adopting a definition as we consider it a contribution of this paper to elaborate the meaning of the term model in our empirical study.

The process of modelling as a derivation of a model from an original is described by Clement (1989) and by Justi and Gilbert (2002) as an iterative, cognitive process. In this process, (mental) models are empirically tested, further developed or changed, and then tested again.

The empirical testing can be made directly with the model or via comparison with data acquired from the original. After the model has been tested, its fit for its purpose has been evaluated, and similarities or differences between model and original are examined, further iterations of this process can follow.

2.2 Students conceptions about models and modelling

Relevant studies about students' conceptions of models and modelling were published for example by Grosslight et al. (1991) and Treagust et al. (2002). Teachers' conceptions of these topics were published for example by Justi and Gilbert (2003) and Crawford and Cullin (2005).

Grosslight et al. (1991) interviewed 7th and 11th grade students about different aspects of models and modelling. In the aspect "kinds of models" almost all students mentioned concrete objects as models for concrete objects. Rarely did they refer to models as representations of ideas or abstract concepts. These students perceive the models to look like the "real" object, but different in scale (mainly the 7th graders). When asked for the "purpose of models", students in Grosslight`s et al. (1991) study identified a wide range of purposes such as: communication, learning and understanding, providing references and examples, observation, making things clear and accessible, etc. Regarding the aspect "multiple models" the majority of the students thought that it is useful to have multiple models for showing different views of the same entity. No student mentioned using multiple models to test different hypotheses.

Questions regarding aspects like "designing and creating models" students of the 7th grade felt that the modeller tries to make the model as close as possible to the exact size, shape and proportion of the real thing. The 11th graders more often mentioned the consideration of "major and minor" importance of attributes of a model. When asked for likely reasons for changing a model the 7th graders mentioned mistakes and changes in the reality, whereas the 11th graders mentioned reasons like new findings through research, experimentation, or discovery. However, they do not consider that the model itself can be a profound part of this research. Grosslight et al. (1991) identify three general levels of thinking about models.

Treagust et al. (2002), who examine students` understanding of models in science (N = 228) during the age of 13 to 15, present in some points results that are corresponding to Grosslight et al. (1991), but Treagust et al. (2002, p. 366) say: "that many students have a good understanding of the role of scientific models in learning science". The need of multiple models is recognized, and the students show "a good appreciation for the changing nature of scientific models". We now want to assess the student's concepts in another cultural and geographical contexts ten respectively twenty years later.

2.3 Scientists conceptions about models and modelling

There are various epistemological attempts trying to clarify, what constitutes a model (Black, 1962; Hesse, 1970; Stachowiak, 1973; Bailer-Jones, 2002; van der Valk et al., 2007; Mahr, 2008 etc.). But the concept is not straight forward. Schwartz and Lederman (2005) present scientists` views of models. In their open-ended survey-based study 70.7% of the 24 natural scientists see models as explanations or a possibility to organise observations that also included testing predictions. Further 37.5% of the participants mentioned the use of models to simplify a complex process or system or as tool to visualise an abstract concept. Nine of the researchers mentioned models as mathematical representations and a few indicated models as a theoretical framework. The study of Schwartz and Lederman (2005) further suggests that the "conceptions of scientific models and their use in science may differ with context of scientific practice".

We therefore assume in our research that the desirable level of model understanding in a learning context can also differ across contexts. However, we aim to identify these different qualities in order to shed light on the breadth of available conceptions of model understanding, their properties and implications.

Bailer-Jones (2002) interviewed nine scientists on the topic of scientific models. She recognizes that the definitions for models are rather diverse. Bailer-Jones (2002) found that models are recognized as representations for phenomena which belong to reality and that they are perceived as a subject to empirical test. Models are simplified and hence enable focussing on the essence. She further identified three dichotomies in the way models are perceived: (1) capturing the essence versus accuracy, (2) satisfying empirical tests versus not being true and (3) being about reality versus only capturing the essence.

2.4 Model competence

Our conception of model competence is suggested as the reflective use of models, which recognizes the tentative, hypothetical and subjective character of scientific models. It can be the meaningful choice of a model, self-creation of a model and also the communication via models (Upmeier zu Belzen & Krüger, 2010).

Model competence enables a learner to autonomously solve problems using scientific models. During the development of model competence, learners are becoming increasingly aware of the preliminary, hypothetical and subjective character of scientific models and hence realise the nature of science (Lederman, 2004). Upmeier zu Belzen & Krüger (2010) developed a theoretical structure of model competence identifying the five aspects: "nature of models", "multiple models", "purpose of models", "testing models" and "changing models". Each of this subdomains is differentiated into three levels (corresponding with Grosslight et al. (1991), Justi and Gilbert (2003), Crawford and Cullin (2005)) with an increasing understanding of models as tools for scientific inquiry. We want to point out, however, that in the context of this study we do not assume that the theoretical structure of model competence is a model of the development of a student – it can also be used as a (context-sensitive) classification.

2.5 Learning and teaching theories

As we pointed out in our introduction, our research is concerned with scientists' and students' conceptualizations of models (cf. Treagust et al., 2002). We assign an important role in reconciling these views to the teacher. In this context, a study of van Driel and Verloop (2002) found that teaching activities are only poorly addressing the students' views of models and modelling abilities.

This mismatch and our focus on the role of the teacher motivate the theoretical approach of educational reconstruction (Kattmann et al., 1997) as our methodological research framework. It addresses the gap by considering existing students' conceptions and aligning them with established scientific conceptions in order to design a learning environment that effects a conceptual reconstruction (cf. Krüger, 2007).

Educational reconstruction assumes a moderate constructivist epistemology (Gerstenmaier & Mandl, 1995; cf. Riemeier, 2007) where knowledge acquisition is viewed as a constructive process that involves actively generating and testing alternative propositions (Tyson et al., 1997). The knowledge is constructed in an active and self-determined process. Starting point for the constructing process are the actual existing conceptions of the learner. This theoretical background helps to understand the learning processes.

A further theoretical influence is the theory of conceptual change (Strike & Posner, 1992; Duit & Treagust, 2003). It is viewed as an outgrowth of the constructivist epistemology (Tyson et al., 1997). Students have a background of central commitments which organises their learning (like scientists). Conceptual change occurs, when these commitments require modification (Tyson et al., 1997). The students have to acquire new concepts and a new way of seeing the world (Tyson et al., 1997). The conditions of conceptual change are intelligibility, plausibility, fruitfulness and dissatisfaction with existing concepts (Strike & Posner, 1992). An active role is played by social and motivational factors in the learning environment (Strike & Posner, 1992). While we are aware of the recent notion of "conceptual reconstruction" and its emphasis on the self-determined construction by students (cf. Krüger, 2007), we maintain the original term conceptual change in the context of this paper.

This theoretical background helps to understand the conditions for conceptual change and therefore also for learning processes.

2.6 Research questions

Following the three elements of educational reconstruction, we structure our research into the following three research questions:

1. What conceptions of models and modelling do students have?
2. What conceptions of models and modelling do scientists have?
3. Which strategies for interventions could be derived from these two perspectives?

In the research project, we examine the following prepositions**:**

- Students mainly perceive models as instruments for visualization and explanation.
- The use of models in a scientific way, and their heuristic functions are not or only rarely recognized by students. More “scientific” conceptions are only expressed by very few students.
- Scientists perceive models as representations for ideas, which are the basis for testing and developing ideas.
- The conceptions of students and scientists are different, but also share some common properties. Their interdependency provides useful sources for deriving interventions.

The scientific concepts are not intended for a direct and systematic comparison with students’ understanding but serve as a sensitizing device and ideal for our qualitative interpretation that highlights sophisticated levels of using and understanding models.

3. Research design

We assume that it could be promising to foster model competence by considering the individual concepts of the students. As noted this idea is recognized by the theoretical background of educational reconstruction (Kattmann et al., 1997). The three components of this framework are put into relation with each other to create more effective lessons: students’ conceptions, the scientific view, and the didactic structuring (Figure 1). The three parts of the research design relate to each other in an iterative way. That means that the design of the learning environment is developed on the basis of the conceptions of students and scientists, but also influences the analysis of the conceptions. Changing the perspectives between the three domains of the research design enables a better focus on each aspect.

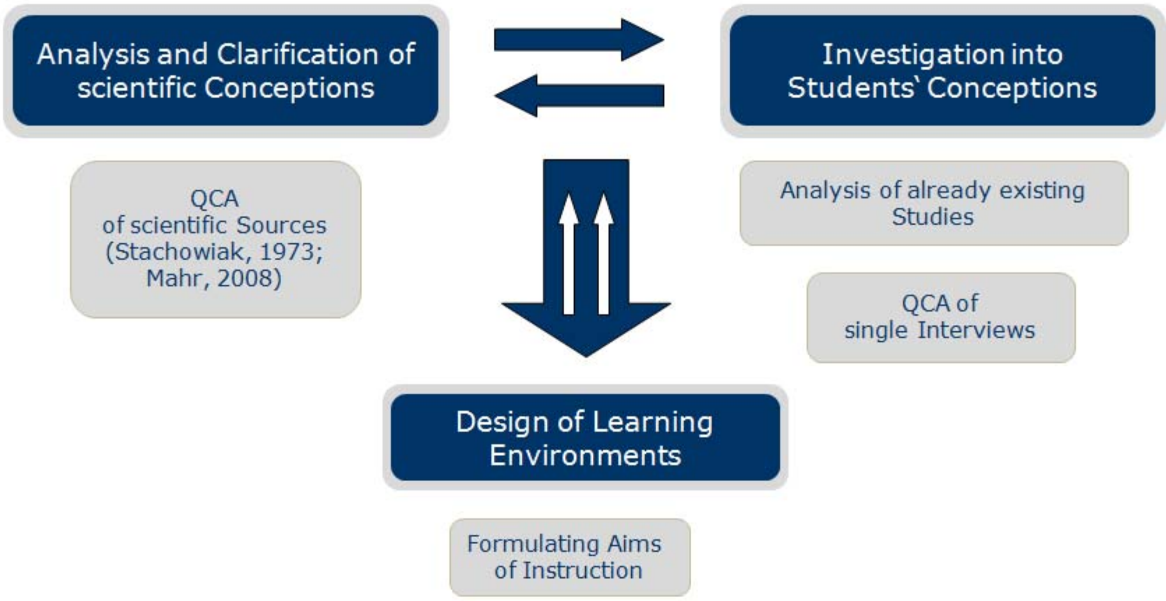

Figure 1. Research Design modified according to Kattmann et al. (1997).

To research the quality of students' conceptions and their influence on using models, we analyse existing findings like the study of Grosslight et al. (1991). Further we collect data in semi-structured individual interviews with students. The main thread of the interviews is based on Grosslight et al. (1991) and is therefore following the sub-domains of the theoretical structure of model competence ("nature of models", "multiple models", "purpose of models", "testing" and "changing"). In the first part of the interviews the students propose own models and express their understanding of them. Then the students get presented some objects, which they should categorize as models or not. Further they should explain why or in which respects something is a model for them or why not. These objects were for example: models related to a biological content, real organisms, preparations of organisms, analogies, pictures of organisms, x-ray prints, microscopic pictures, and models related to chemical or everyday content.

The interviews are audio-recorded, then fully transcribed and copy-edited. The interviews are coded using qualitative content analysis (Mayring, 2003) with the help of MAXQDA. All interviews were coded by a second coder and a discursive validation was carried out until an agreement was achieved. After that for every subdomain (like "nature of models"), the interviewees' statements were sorted, expatiated and structured into single concepts (Gropengießer, 2005).

Parallel to that, we assemble established scientific conceptions from academic literature via the same procedure as described above (QCA with the help of MAXQDA).

For this article we draw on seven single-interviews (age 15 to 20/grade 10-13, male and female students from German school types 'Gymnasium' and 'Realschule') that were selected to create a maximum of diversity and breadth.

4. Results and discussion

We now present our empirical findings with illustrative and representative quotes. For example, Paula responds to an object representing a maple fruit: "*It is a model if you know what it is. It is a model, because you can´t notice more on the parts of the tree than you can see here and that`s why it is a model.*" For Paula something can only be a model, if you know what it is, that means if there is an original, where you can refer to. Further a model should be quite close to the original (it`s a model, because you can`t notice more on the original-"nature of models"). She represents the idea of a model as a copy of the original.

For Oliver (class 10) a model: "*is made in a smaller scale than the real thing, which has to be explained with the model. It's used to illustrate and for better explanations*". Further he said: "*They help to explain processes on very small objects, which are invisible for the human eye.* […] *Models are useful for better explanation and better understanding".*

It is a very central aspect for Oliver, that the model has a different scale than the original ("nature of models"). Models are used to visualize and to explain ("purpose of models"). Models make things also accessible ("purpose of models"). The concepts of Oliver are comparable to the findings of Grosslight et al. (1991), in which the main focus of the students` conceptions lies in understanding and explaining.

When Lena (class 11) was interviewed about her definition of a model, she answered: "*A model is an idealised - a replica of something - of a process or an object, an idealised idea of something, which for example exists in the nature. The model helps to represent how it works, without imitating the real world. It isn't the real world*".

She emphasizes that the model is idealised and is not the real world ("nature of models"). In a later phase of the interview she differentiates between models used as teaching aids at school and scientific models. Models for school contexts are used to illustrate and to explain via representing ("purpose of models"). On the other hand she reflects on scientific models: "*Researchers want to go a step further, they want to see further, want to discover more and new things. Whereas for students the known, the discovered is explained with models*". These quotes show how elaborated Lena is thinking about models. On an abstract level she realises the idealised and hypothetical character of models. This finding is corresponding with Treagust et al. (2002). However, once Lena is relating to concrete school contexts, her comprehension of model functions is limited to visualization and explanation: "*Models help to simplify the life, for better comprehension, for faster learning. Also when the original is not accessible, the model can help the teacher to show these things in a smaller scale*". This is corresponding with Grosslight et al. (1991). She seems to not apply her relatively sophisticated and abstract understanding of the nature of models to concrete school contexts, where often only "prepared" models are presented. Treagust et al. (2002) proposed that the mismatch between the abstract realisation of the role of models and the limited application in concrete contexts could be related to a lack of opportunities to use models effectively and applicably in school. Based on our data we hence suggest that special interventions should be targeted in developing from an abstract awareness of the nature of models towards a concrete application in a school context.

If we examine central scientific concepts, models depict something ("purpose of models"), models are reduced (selectively and subjectively- "nature of models") and they are pragmatic (a model for whom, for when and what for – "purpose of models"). It is also a scientific concept that a model is a transporter for a special cargo, i.e. its content. For Mahr (2008) it is very central that nothing is a model per definition, but that something becomes a model by a judgement.

In Table 2 examples of the detected conceptions of both groups are presented across the sub-domains. On the one side we have students, who think that there is no big difference between model and original. We also have students who think that a model is a hypothesis ("nature of models"). But at the end there remains a difference; students believe that there are hypotheses when the object is still not finally clarified. But from their point of view the research process has an end. The scientists know that there is no final state and the findings always remain a possibility. This different conceptualization can also be related to the "purpose of models". Students have rather vague concepts, when they say; models are for experimenting or for getting insights about reality. However, they don't have concrete conceptions of how this can be utilized, for example for finding and testing hypotheses.

Regarding „changing of models", we have students who think that a model can be valid for ever. That means there is no need for changing the model. Also the model will be changed, when the original has changed. But they are not aware that changing a model is an opportunity to get more insight, and that not only the new insight is represented in the changed model. The scientist is aware of the fact that changing the model leads to a change of understanding the original.

The concepts which are different in both groups are interesting, because they help to understand where the students need support and in which direction interventions need to aim. The concepts which we can find in both groups could be a promising starting point for developing intervention guidelines respectively interventions.

Table 2. Examples of selected concepts of students and assessment to what extend these meet the scientists' conceptions. Bold headings reflect the subdomains from the theoretical structure of model competence

Students	**Scientists**
“Nature of models”	
There is no big difference between model and original.	
A model is idealised.	A model is idealised.
A model is an imagination.	A model is an imagination.
A model is a hypothesis.	A model is a hypothesis.
	A model is a hypothetical possibility.
Everything could be a model.	Something becomes a model by a judgement.
“Multiple models”	
There is only one model for one original.	
There are M.M. because you need an alternative if one is broken.	
There are M.M. for showing different aspects of the original.	There are different model-objects for one model.
There are M.M., because there a different target groups.	
There are M.M. because there are different hypotheses.	
There are M.M. to advance science.	
„Purpose of models“	
Models are for decoration.	
Models are for hobbies.	
Models are for visualization.	Models are for representation. Models have didactic purposes.
Models are for explanation.	
Models are for understanding.	
Models are for orientation.	Models are for orientation.
Models make things accessible.	
With models you can experiment.	
With models you can get new insights about the reality.	With models you can get new insights about the reality.
	Models are mediators.
	Models are for finding and testing hypotheses.
	Models are for scientific theory-building.

"Testing of models"	
	You test the model, regarding his function as a transporter.
You test models via trying if they are working.	
You test models via experimentation.	
You test models via discussion.	
You test a model if it is understandable.	
You test the validity of a model regarding its fit with the original.	You test the validity of a model regarding its fit with the original.
Testing the model brings new insight about the original.	
"Changing of models"	
A model can be valid for ever.	
~~A model can be valid for ever.~~ *	
A model has to be changed if it is not understandable.	
A model has to be changed if it is erroneous.	
A model has to be changed if the original has changed.	
A model has to be changed if there a new insights about the original.	A model has to be changed if there a new insights about the original.
	A change of the model leads to a hypothetical change of the original.

* Negative formulated concepts are formulated positive and crossed out.

5. Outlook

Based on our analysis of the detected concepts one objective for the development of intervention guidelines is to make the students aware of the tentativeness of science via the tentative character of models. There should be an emphasis on the meaning of multiple models for one original as different hypotheses for one original. Also the modelling process itself should be a main part of the inquiry process in science subjects. Such insights should then be applied for constructing learning environments that fostering model competence in a more differentiated way.

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8 HOW YEAR 7 TO YEAR 10 STUDENTS CATEGORISE MODELS: MOVING TOWARDS A STUDENT-BASED TYPOLOGY OF BIOLOGICAL MODELS

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Abstract

The present study aims to provide a typology of biological models which is based on students' perspectives and which, therefore, might be useful for researchers and practitioners in science education. Based on the repertory grid technique, students (*N*=19) were asked to categorise model-triads by communicating both the similarity between two models and the way in which the third model differed from these. Each identified perspective was analysed and transformed into an item by formulating a short sentence describing the perspective. Within a quantitative approach (*N*=725), these items could be summarised as four factors ('replication', 'illustration', 'explanation', and 'prediction') which served as criteria to classify 16 biological models. Using this data, a cluster analysis of the 16 biological models (as cases) created three types of biological models: 'iconic models' (mainly three-dimensional, material models), 'explanatory models' (mainly diagrams and drawings), and 'strange models' (a non-homogenous cluster including, e.g., a model organism). Based on the findings it is recommended, e.g., to consider different types of models when assessing students' understanding of models and modelling in science education research and that each model-type has its own value when discussing models in biology classes.

Keywords: biological models, classification, typology

1. Introduction

The importance of models for scientific enquiry (e.g. Frigg & Hartmann, 2006; Harré, 1970) and science education (e.g. Gilbert & Boulter, 1998; Gilbert, Boulter, & Elmer, 2000; Oh & Oh, 2011) is recognised in the literature. As a basis for theoretical reflections about models in science (e.g. Harré, 1970) as well as in science education (e.g. Boulter & Buckley, 2000), several model classifications have been proposed in literature. For example, Harré (1970) argues that some kinds of models are used to explain things or processes that are already known, whereas other kinds of models are used to develop new (hypothetical) knowledge regarding a certain phenomenon. In science education, model classifications might be used as a theoretical framework for the selection of teaching contexts as they might 'alert teachers and writers to the conceptual demands of the different model[s]' (Harrison & Treagust, 2000, 1014). However, there are a number of different model classifications which are based on different criteria and therefore provide different classes or types of models (e.g. Boulter & Buckley, 2000; Buckley, Boulter, & Gilbert, 1997; Harrison & Treagust, 2000). Hence, it is difficult for researchers and practitioners in science education to decide which classification to use as theoretical framework. Furthermore, it is argued that students' perception of models is likely to differ from experts' point of view (Harrison & Treagust, 2000). Therefore, the present study aims to provide a classification of biological models which is based on students' criteria and might therefore be useful for science teaching and research in science education.

2. Theoretical background

2.1 Concerning the notion of classification and typology

According to Bailey (1994), the term *classification* can be seen as the sorting of objects based on their similarity using one single criterion. Furthermore, a classification should be exhaustive and exclusive. In comparison, the term *typology* is used for a multidimensional and conceptual classification: Objects are classified using more than one criterion, resulting in various *type concepts* which are not necessarily empirical cases (Bailey, 1994; Capecchi, 1968). The key issue of classifications and typologies is the selection of criteria because all classifications and typologies depend on the respective criteria (Bailey, 1994).

2.2 Classifications of biological models

There are different model-classifications in literature which may be distinguished due to the criterion they use to classify models. A *semantic* classification of models refers to their representational function (Frigg & Hartmann, 2006). One semantic classification is provided by Frigg and Hartmann (2006) who distinguish between representational models and models of theory. While the former represent 'a part of the world' (741), the latter are said to be a structure which satisfies all propositions of a theory.

An *ontological* classification of models points out the fact that the model object can differ in itself, i.e. that a model can have different modes of representation (Boulter & Buckley, 2000).

For example, Boulter and Buckley (2000) put forward concrete models (i.e. material models), verbal models, visual models, mathematical models, and gestural models. The authors emphasise that there are many models which are composites of more than one mode of representation.

According to the *epistemology* it is possible to distinguish models based on their role in the process of model development. In accordance with Gilbert et al. (2000), there are primarily mental models, expressed models, scientific models, historical models, and teaching models.

3. Research questions

The aim of this research is to develop prominent perspectives which are used by students to classify biological models and to distinguish different *type concepts* of models based on these perspectives. Two research questions are addressed:

1. Which perspectives are used by students to classify biological models?
2. To what extent is it possible to develop different *type concepts* of models based on students' perspectives?

4. Method

The research was based on the repertory grid technique (Kelly, 1955). The repertory grid technique uses a two-step approach to elicit the perspectives ('constructs'; Kelly, 1955) which are used by subjects to structure their surroundings (Fransella & Bannister, 1977): First, several elements (e.g. biological models) are presented to respondents to elicit their personal constructs. Secondly, respondents characterise all elements by using the elicited constructs. Kelly (1955) emphasises that a selection of the elicited constructs can be used in the second step.

In this research the *development of perspectives* was performed qualitatively (*N*=19; students from secondary school; 12 to 17 years old; school year 7 to 10; from Berlin, Germany). The *characterisation of elements* was carried out quantitatively based on a larger sample (*N*=725; students from secondary school; 11 to 18 years old; school year 7 to 10; from Berlin).

4.1 Developing perspectives

We selected 28 elements (i.e. pictures as representations of biological models; cf. Appendix) which cover different kinds of models as described in literature (e.g. Boulter & Buckley, 2000; Harrison & Treagust, 2000). The models were presented to students from Berlin (Germany) in triads and randomly drawn out of this pool of the 28 models. Ten triads were consecutively presented to each student. To complete the tenth triad two randomly selected models were used for a second time. On each occasion the students were requested to select two models that are alike and to separate these from the third model. Furthermore the students had to name the criteria they referred to when arranging the models (construct and contrast pole; Kelly, 1955). The interviews were recorded and the mentioned constructs and contrast poles were noted during the interviews.

The constructs were analysed and deductively coded based on existing perspectives (Mayring, 2000). As a starting point, the coding agenda of Meisert (2008) was used since it was developed inductively based on students' responses and should therefore be applicable to analyse students' constructs. However, Meisert (2008) asked her respondents whether or not something is a model and therefore restrained the students' answers a priori to this point of view. Consequently, it was predictable that new perspectives would be found.

4.2 Characterising biological models

The identified perspectives were transformed into 15 statements and a four point rating scale was added (not at all – hardly – mainly – totally). Due to economic reasons, 16 of the 28 models were selected, resulting in 16 models (cf. Appendix) each to be characterised using the 15 statements (cf. Table 2). A balanced incomplete block design with t=16, b=30, r=15, k=8, and λ=7 was developed to reduce the number of models to be characterised for each student from 16 to eight (Giesbrecht & Gumpertz, 2004).

For the purpose of data reduction, an exploratory factor analysis was performed using the complete data (i.e. regardless of which model had been characterised). This resulted in a plausible four factor solution. Therefore, the 15 statements were converted into four factors.

The mean score in the four factors was calculated for all 16 models. A cluster analysis including the 16 models as cases characterised by the four mean scores was undertaken to develop *type concepts* of models with homogenous mean scores within the four factors.

5. Results

5.1 Developing criteria

As suggested by Kelly (1955) not all elicited constructs were selected for the characterisation of models. Especially, constructs which referred to the models' modes of representation or to the corresponding original were excluded because minimal variance was expected. According to the *mode of representation* the students used diverse criteria to categorise the models. For example, some students set model organisms apart from diagrams, while others distinguished between dynamic and static models. The perspective *original* was used to compare the models due to their subject (Harré, 1970).

Table 1 shows the 15 selected perspectives and the corresponding statements. Some students described models as *real models*. The students most often referred to semantic perspectives when categorising the models. Several students mentioned that the model was smaller or bigger than the original (*size*), that the model was a *simplification*, or that there were *differences* between the model and the original. Students described models which showed *assumptions* and some which showed *knowledge*. Models which represented a *process* or a *relation* were also described. Epistemologically, the students categorised the models based on their use *to depict*, *to focus* on, *to explain*, or – more generally – *to find out* new things about the original. The suitability of models for *school* was identified for different reasons but especially because of the models' size or complexity. Finally, none of the interviewed students categorised the models by referring to the use of models in developing *hypotheses*. This perspective has been described by Meisert (2008) and is also an important feature of models in theoretical literature (cf. Krell, Upmeier zu Belzen, & Krüger, 2012; Oh & Oh, 2011). A statement describing this perspective was therefore added (Table 1).

Table 1. The perspectives used by the students to categorise the 28 biological models

	Perspective	Statement
OT	real model	*To what extent do you agree that this is a model?*
semantic perspectives	size	*This model shows [the original] in a smaller or bigger size.*
	simplification	*This model is a simplification of [the original].*
	differences	*This model is different from [the original].*
	assumptions	*This model shows what is assumed about [the original].*
	knowledge	*This model shows what is known about [the original].*
	process	*This model demonstrates processes within [the original].*
	relation	*This model demonstrates relations within [the original].*
	replication	*This model looks like [the original].*
epistemological perspectives	to depict	*The model is used to depict [the original].*
	to focus	*This model is used to represent specific characteristics of [the original].*
	to explain	*This model is used to explain [the original].*
	for school	*The model is suitable for school.*
	to find out	*This model is used to find out new things about [the original].*
	to hypothesise[#]	*This model is used to develop assumptions about [the original].*

Note. The statements were translated from German by the authors. OT: Ontological Perspective. [#]: This perspective was added because of its theoretical importance.

5.2 Characterising Biological Models

In summary, each student characterised eight models based on the 15 statements (Table 1). As the factor analysis was carried out for the complete data (i.e. regardless which model was characterised) it was finally done based on N=5,575 characterisations. A principal component analysis of the data with varimax rotation was performed. The overall KMO measure was .88

('great'; Field 2009), for individual items >.71 ('good'). Bartlett's test ($\chi^2(105)=16249.09$; $p<.000$) indicated that correlations between items were sufficiently large. Four factors had eigenvalues of >1 and in sum explained about 55% of the variance. Table 2 shows the factor loadings after rotation, values <.30 are not shown.

Table 2. The results of the factor analysis (N=5,575)

Statement	**Explanation** Factor 1	**Illustration** Factor 2	**Prediction** Factor 3	**Replication** Factor 4
This model is used to explain [the original].	.71			
This model shows what is known about [the original].	.68			
This model shows what is assumed about [the original]	.62			
This model demonstrates relations within [the original].	.62			
This model demonstrates processes within [the original].	.59			
This model is a simplification of [the original].	.33	.63		
To what extent do you agree that this is a model?		.61		
This model shows [the original] in a smaller or bigger size.		.58	.49	
The model is used to depict [the original].	.33	.58		.41
The model is suitable for school.	.39	.54		
This model is used to represent specific characteristics of [the original]	.35	.37	.35	
This model is used to find out new things about [the original].			.74	
This model is used to develop assumptions about [the original].	.41		.65	
This model is different from [the original]. (differences) [#]				.87
This model looks like [the original].		.36	.32	.69
variance (%)	19.27	14.47	10.46	10.17
consistency	α=.74	α=.69	α=.57 (r=.40**)	α=.54 (r=.38**)

Note. Cronbach's α or Pearson's r were used as a measure of consistency. In the questionnaire, the placeholder [the original] was replaced by the respective original. Items which have been selected for each factor are highlighted. [#]: This item was negatively coded for the factor analysis.

The items in each factor suggest naming factor 1 'explanation', factor 2 'illustration', factor 3 'prediction', and factor 4 'replication'. The item *to focus* was added to the second factor but it loads relatively high on the first (0.347) and third (0.346) as well.

As mentioned above, models can be classified based on different criteria. Because a classification is a one-dimensional system for the categorisation of objects (Bailey, 1994) each factor may be used as a student-based criterion for classifying the biological models.

For each model the mean scores of the four factors were calculated (Table 3). The results show that the mean score of 'illustration' is >2.5 for all models except models M15 and M16 and the mean score of 'prediction' is <2.5 for all models except model M12. Regarding the factor 'replication', the mean scores are >2.5 for eight models, five of them may be referred to as scale models and three as diagrams (cf. Appendix). The standard deviation indicates that the variance is relatively small for the factor 'prediction' (sd=0.14) but larger for the other factors (0.28≤sd≤0.46).

Table 3. The mean scores of the four factors for all 16 models

Model	Explanation	Illustration	Prediction	Replication
(M1) predators and prey (circuit)	3.06	2.86	2.39	2.83
(M2) human arm	2.97	2.94	2.32	2.37
(M3) photosynthesis	2.94	2.57	2.18	2.32
(M4) human mouth	2.92	2.85	2.33	2.05
(M5) biomass	2.84	2.90	2.45	2.44
(M6) predators and prey (curve)	2.82	2.68	2.44	2.61
(M7) crossbreeding	2.79	2.75	2.43	2.64
(M8) dragonfly	2.71	2.97	2.37	2.72
(M9) flower	2.65	3.08	2.36	3.15
(M10) cell membrane	2.57	2.89	2.38	2.78
(M11) *Homo neanderthalensis*	2.50	2.69	2.57	3.14
(M12) palm leaf	2.36	2.81	2.22	2.45
(M13) plant seed	2.29	2.70	2.35	2.68
(M14) environmental disaster	2.52	2.54	2.29	1.80
(M15) human heart (textual model)	2.20	1.77	1.98	1.50
(M16) *Aplysia californica* (organism)	2.17	2.22	2.22	1.96
ms	2.64	2.70	2.33	2.46
sd	0.28	0.32	0.14	0.46

Note. The shades of grey show models in one common cluster (cf. Figure 1).

Unlike a classification, a typology is multidimensional and conceptual (Bailey, 1994). The 16 models were therefore used as cases and the four factors as criteria to develop student-based model *type concepts*. A common method for developing a typology is the cluster analysis (Romesburg, 1984/2004).

The mean scores of the four factors for each model (Table 3) have been analysed in a hierarchical cluster analysis using the Ward algorithm (Romesburg, 1984/2004; Wishart, 2006). The cophenetic correlation (r=.77) indicates a strong match between the clustering tree and the Euclidean distances between the 16 models (Romesburg, 1984/2004). The hierarchical cluster analysis suggests that three clusters represent the data appropriately. The best three cluster solution (Figure 1) was replicated in about 70 % of 1,000,000 trials with random starting conditions ('focal point clustering'; Wishart, 2006).

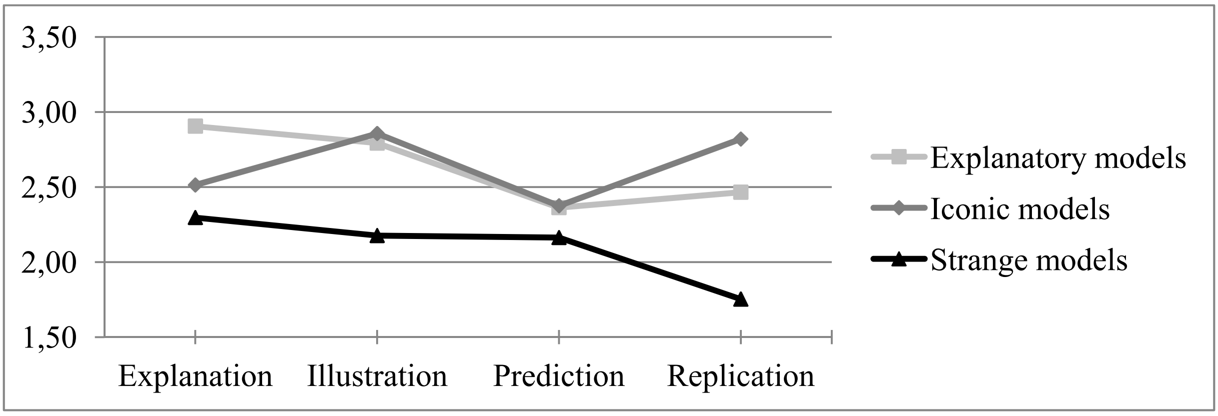

Figure 1. Cluster values in the four factors.

The 'explanatory models' cluster includes models M1 to M7, cluster 'iconic models' covers models M8 to M13, and cluster 'strange models' accounts for models M14 to M16 (cf. Appendix). To highlight the high values of the first two clusters concerning 'explanation' and 'replication', the first cluster was named 'explanatory models' and the second cluster 'iconic models'. Consistently, cluster 'explanatory models' includes models which are somewhat abstract, e.g. diagrams or drawings, and cluster 'iconic models' includes models which represent the outer shape of the original more accurately. The third cluster was called 'strange models' because the mean scores of all factors are <2.5. The three models which belong to this cluster may in fact be seen as strange models from the students' points of view: A model of the population bottleneck (M14), a statement which was included in the survey to illustrate that models do not have to be in the concrete mode (M15), and a model organism (M16).

'Explanatory models' and 'iconic models' only differ significantly in the factors 'explanation' (p<.05; d=1.34) and 'replication' (p<.01; d=2.93). These two clusters can be seen as homogeneous since the standard deviations of the factors within the clusters are smaller than the overall standard deviation of the four factors. Regarding 'strange models' this only applies to 'explanation' and 'replication' but not to 'illustration' and 'prediction'. Furthermore, the cluster 'strange models' has mean scores which are significantly smaller than the mean scores of the other two clusters ($p<.05$; $1.32 \leq d$). The only exception are the mean scores of 'iconic models' and 'strange models' concerning 'explanation' with $p=.12$.

6. Discussion

Before discussing the findings, some methodological constraints have to be made. First, the *development of perspectives* was done qualitatively based on a rather small sample ($N=19$). However, each student got ten model triads and was requested to name construct and contrast pole (Kelly, 1955) each time. Hence, in total, the students were requested to name construct and contrast pole 190 times. Furthermore, an already developed coding scheme was used (Meisert, 2008) and only a few new perspectives were found. However, asking more students may result in additional perspectives. Second, 28 models were selected for the development of criteria and 16 models were characterised in the quantitative step. The models were chosen in such a way that a wide range of different models was covered (cf. Appendix). Buckley et al. (1997) developed a model-typology by analysing different models of the heart and the lunar eclipse which are used in schools. The authors point out:

> The selection of examples from just two phenomena of science education may reduce its [the model-typology's] value. The two phenomena used are of human scale and of much larger scale. The examination of models of phenomena at much smaller and less accessible scale [...] or those that take place over long time spans [...] may result in elaborations or revisions of the categories and criteria we have used (101-102).

In the present study a much wider range of different models was used. But the general argument still remains: Using even more models could result in even more perspectives. However, due to economic reasons as well as the practicability of the study, a constraint had to be made. Nevertheless, further research could take the findings of the present study up and potentially reveal additional model *type concepts*.

The student-based perspectives could be assigned to three broad dimensions which have already been described in literature (Frigg & Hartmann, 2006): *ontology*, *semantic*, and *epistemology*. The epistemological perspective *for school* could not be described clearly because the students saw the models as suitable for school for different reasons, e.g. with reference to the models' sizes or complexities. The dichotomy school model vs. scientific model seems to be important for students' understanding of models. For example, Treagust, Chittleborough, and Mamiala (2002) argue that students' understanding of the nature of models may be more effectively fostered when discussing (abstract) scientific models than when making use of school models. Certainly more research is necessary to shed light on the question of whether primarily ontological perspectives are used by students to decide if a model is seen as suitable for school or not.

The perspective *to hypothesise* was not consulted by the interviewees. In fact, some students explained that a model shows *assumptions*. Since, in these cases, the relationship between the model and the original rather than the enquiry process was in the focus of the students, this perspective was added to the semantic dimension (Table 1). During the interviews, students classified three-dimensional, concrete models as *real models* and set them apart from *model organisms* or *diagrams*, for instance. These results support the findings of others and underline that students seem to associate the term model primarily with concrete entities (e.g. Ingham & Gilbert, 1991). Thus, the diversity of models – including concrete models as well as more abstract entities – is apparently not entirely recognised by students. Consequently, it might not only be important to learn how to model but also to learn models in different modes of representation and to learn about models and modelling (Gilbert & Boulter, 1998).

The overall data was reduced to four factors describing the extent to which a model is seen as ‘explanation’, ‘illustration’, ‘prediction’, or ‘replication’. The first three factors reflect different purposes of models as described, e.g., by Krell et al. (2012): describing, explaining, and predicting. Compared to this, the factor ‘replication’ refers to the model’s ontology and reflects the similarity between the model and the original. The three diagrammatical models (M1, M6, and M7) have comparatively high mean scores in this factor, which indicates that students seem to understand diagrams as accurate representations of the respective phenomena (i.e. with a high degree of ‘positive analogies’; Hesse, 1966). Consequently, the notion that diagrams are also representations which are highly idealised might be discussed in school. Visual models (M1 to M7) in particular have high values in the factor ‘explanation’, which seems to hint at the fact that models in this mode of representation (Boulter & Buckley, 2000) are seen as more explanatory than other models by students. The factor ‘illustration’ has the highest mean score (*ms*=2.70; *sd*=0.32), which shows that the 16 models are mostly seen as an ‘illustration’ and includes, amongst others, the perspectives *real model*, *to depict*, and *for school*. This may be a hint to students’ dominant understanding of models as entities to visualise something in school (Ingham & Gilbert, 1991). Finally, students seem to understand the ‘predictive nature of models’ (Treagust, Chittleborough, & Mamiala, 2004) only to a relatively small extent (*ms*=2.33; *sd*=0.14) which corresponds with the conclusion of others (e.g. Grosslight, Unger, Jay, & Smith, 1991).

Three clusters were developed by analysing the 16 models’ mean scores in the four factors (Figure 1). The two clusters ‘explanatory models’ and ‘iconic models’ may be seen as model *type concepts* because they are homogeneous clusters. This is not the case for the ‘strange models’ cluster. This cluster has mean scores of <2.5 in the four factors, indicating that students do not think that the student-based perspectives when categorising models are applicable to the ‘strange models’. This cluster may therefore be an artefact including entities which do not meet the requirements of models from the students’ points of view. The cluster ‘explanatory models’ includes diagrams (e.g. M6) and functional models (e.g. M2) in the visual mode of representation (Boulter & Buckley, 2000). The cluster ‘iconic models’ includes scale models (e.g. M9) as well as functional models (e.g. M12) which are seen as representations with a high degree of ‘positive analogies’ (Hesse, 1966) concerning the original’s shape. Almost all models (except M10) in this cluster are three-dimensional, material models (‘concrete mode’ of representation; Boulter & Buckley, 2000).

The two *type concepts* suggest that students might understand some models as being 'iconic' but others may be seen as 'explanatory'. In general, a typology provides researchers in the field of models and modelling in biology education as well as teachers with a student-based classification of biological models which allows them 'to rise above individual, difficult to compare instances and consider them in terms of conceptual categories' (Buckley et al., 1997, 90). Bailey (1994) emphasises: 'Although typologies are often seen as purely descriptive (rather than explanatory) tools, they often provide for the study of relationships and even the specification of hypotheses concerning these relations' (14). Hence, when trying to assess students' understanding of models and modelling (cf. Grosslight et al., 1991; Krell, 2012; Treagust et al. 2002, 2004) one should consider the effect of the respective model (Krell et al., 2012). A reference to only one type of models in questionnaires or interviews (e.g. three-dimensional, material models) may give researchers an insight into students' understanding of this *type concept*. In contrast to such an approach, a broad range of models may be implemented in assessment instruments to analyse the consistency of students' understanding within and between different types of models.

7. Educational implications

Regarding models and modelling, three major educational aims are proposed in literature. Students should learn (1) major scientific and historical models, (2) about the nature of models and modelling, and (3) to produce and revise models (Gilbert & Boulter, 1998; Justi & Gilbert, 2002). The present findings support some hints for teaching about models and modelling in biology education which concern (1) and (2), i.e. the learning *of* models and the learning *about* models.

First, the findings suggest that students primarily view three-dimensional, concrete models as *real models*. Opposed to this, models in other modes of representation, e.g. model organisms or diagrams, were not seen as models in the same manner. Consequently, teachers may not only discuss concrete models but also model organisms or more abstract models in biology classes to illustrate the diversity of biological models. As there are common characteristics of scientific models (e.g. the relation to a target; Van Der Valk, Van Driel, & De Vos, 2007), it should be discussed why such diverse entities like material objects, diagrams, and organisms are called models. Above that, the present findings as well as other authors (e.g. Grosslight et al., 1991) propose that students understand the predictive nature of models only to a relatively small extent. However, since this is one major purpose of models in biology (cf. Krell et al., 2012) students should be aware of it as a part of the nature of models and modelling in science. Consequently, teachers may explicitly discuss not only the descriptive nature but also the predictive nature of models (Treagust et al., 2004). Finally, as the present study aimed at developing a student-based typology of biological models, one additional educational implication may be highlighted. As discussed in other areas of science education (e.g. Urhahne, Kremer, & Mayer, 2011), the nature of models may be easier to understand in some contexts than in others. This is also highlighted by Harrison and Treagust (2000) who emphasise that different model types put different cognitive demands on students. The present findings suggest that, e.g., the explanatory power of models is better understood in the context of abstract models (‘explanatory models’; Figure 1) than in the context of concrete models (‘iconic models’). Consequently, teachers may use ‘explanatory models’ to introduce this part of the nature of models. In the same sense, single models have a comparatively high mean score in the factor ‘prediction’ and therefore seem to be appropriate to introduce the predictive nature of models in biology classes, e.g. the theoretical reconstruction of *H. neanderthalensis* (*ms*=2.57). Hence, the proposed typology of biological models may guide the selection of models (i.e. of learning contexts) to introduce the multifaceted nature of models in biology classes.

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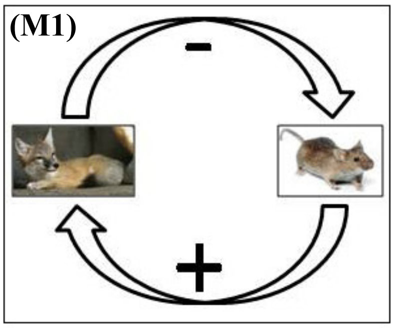
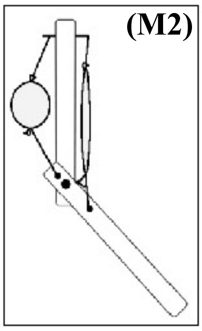
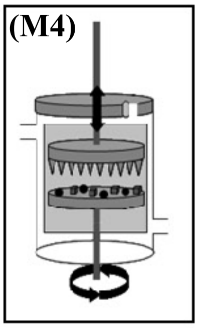
Appendix

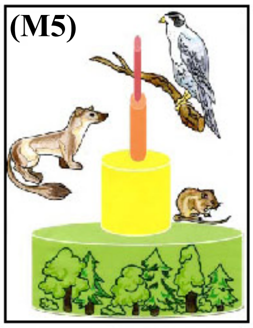
Pictures of the 16 models which have been used for characterising biological models. The models are numbered like in Table 3, i.e. arranged by their mean score in factor 1 (Table 2).

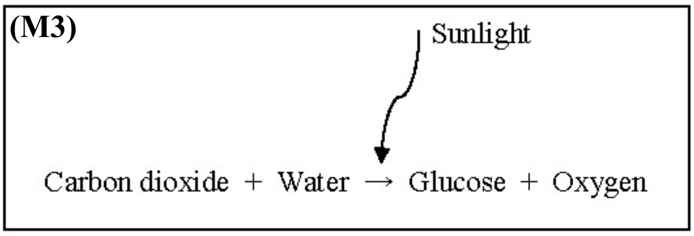
©: M1: Left picture by C. Burnett. M8: Eisma (2012). M13: Ökopark Hartberg.

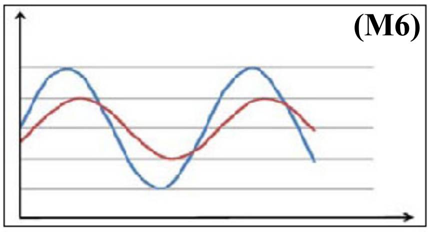


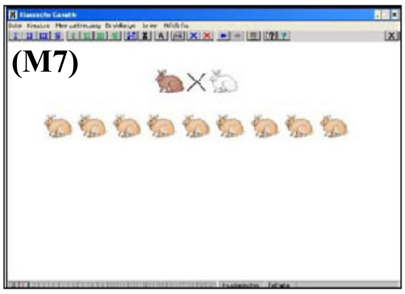


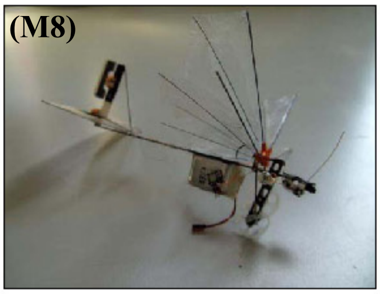


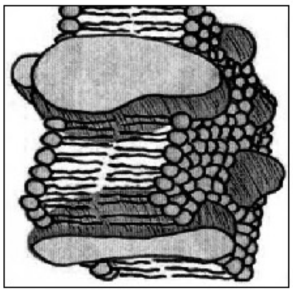












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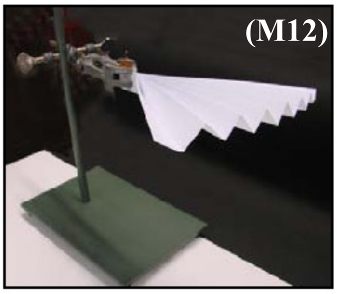

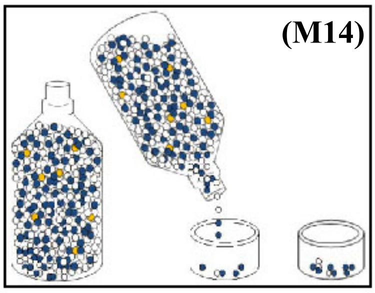

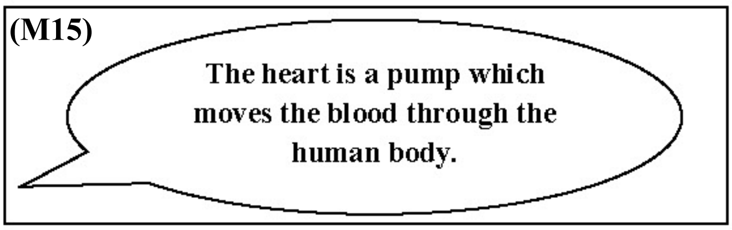

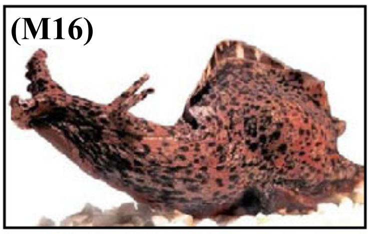

SECTION 4

Teaching: Teaching strategies, teaching socio-scientific issues and curriculum development

9 DEVELOPING THE ABILITY TO CRITIQUE IN THE COURSE OF INQUIRY-ORIENTED PROGRAMS IN BIOLOGY

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Abstract

Authentic scientific practices are designed to facilitate students' understanding of how scientific knowledge develops, including the ability to critique, which constitutes an important part of scientific inquiry. Students should be able to identify potential weaknesses and flaws in scientific claims, articulate the merits and limitations of peer views and read media reports in a critical manner. Even though the importance of incorporating critique in science education classrooms is well accepted and emphasized by the science education research community, much debate still remains regarding how this practice should be taught. We set out to explore the contribution of an inquiry-oriented program for high-school students which emphasizes critiquing. Pre- and post-questionnaires were administered to students participating in an inquiry-oriented program (Bio-Tech), and to students who were not participating in the program. Students of both groups tended to be more in agreement with an arguable claim presented to them in the post-questionnaires compared to the pre-questionnaires. However, the Bio-Tech students tended to use more arguments and focused more on the experimental process described to them than the Control group students. These results indicate that students can develop some critiquing abilities in the context of an inquiry-oriented program in biology.

Keywords: Inquiry; Critique; Scientific practice; Authenticity; Argumentation

1. Introduction

Most recent policy documents present the ongoing call for successful implementation of authentic scientific practices in science classrooms (European Commission, 2007; National Research Council [NRC], 2000, 2012). The ability to practice inquiry requires that students not only learn the traditional process skills, but also combine them with scientific knowledge, reasoning and the ability to critique. Authentic scientific practices include not only skills but also specific knowledge required for investigating and building models and theories about the natural world (National Research Council [NRC], 2012). Much emphasis is directed to the social and cognitive aspects of the scientific process: the communication, argumentation and model-generating practices. Authentic scientific practices are designed to facilitate students' understanding of how scientific knowledge develops, and of 'scientific habits-of-mind' and engagement in scientific inquiry (National Research Council [NRC], 2012; Osborne, 2010).

The ability to critique is generally defined as "reasonable reflective thinking that is focused on deciding what to believe or do" (Ennis, 1987). The ability to critique makes up an important part of scientific inquiry and consists of overlapping skills and abilities, such as testing hypotheses, designing experiments and drawing conclusions from results (Berland & Reiser, 2009; Ford, 2008). Students should be able to identify possible weaknesses and flaws in scientific claims, articulate the merits and limitations of peer views and read media reports in a critical manner (National Research Council [NRC], 2012). The ability to critique is crucial for productive participation in scientific practice and discourse (National Research Council [NRC], 2007). Berland and Reiser (2011) considered critiquing to be a key part of the goals of sense-making and persuasion in scientific argumentation.

Critiquing is strongly connected to the practice of argumentation, which is one of the central goals of science education and the focus of several recent articles and policy documents (Berland & McNeill, 2010; National Research Council [NRC], 2007, 2012; Osborne, 2010). Argumentation is connected to other scientific skills and abilities, such as reasoning, critical and logical thinking, language skills, communication and justification. An argument is defined as an assertion or conclusion with justification, reasons and support (Osborne et al., 2004). Ford (2008) reported that scientists are more likely to have less confidence in a given scientific claim and that their critique mostly concerns the methods used to collect the data and the analysis and evaluation of the results. Non-scientists, on the other hand, are more likely to accept the given scientific claims and relate their reasoning arguments mostly to their personal experiences. In a more recent work, Ford (2012) claimed that constructing and critiquing arguments are fundamental parts of scientific sense-making during engagement in scientific discourse.

Even though the importance of incorporating critique in science education classrooms is well accepted and emphasized by the science education research community, much debate still remains on how this practice should be taught. Osborne (2010) argued that students in contemporary classrooms lack the opportunity to develop and master their abilities to reason out and critique scientific claims. It was suggested that students rarely have opportunities to be engaged in critiquing and in scientific argumentation because traditional approaches to science instruction do not promote or support student engagement in scientific argumentation (Sampson & Clark, 2011). Others indicated that students, in general, lack the abilities to construct and present arguments and are poor at addressing different points of view regarding learned scientific issues. It was claimed that more activities are needed to develop these abilities in the classroom, mainly by restructuring current science lessons (Berland & Reiser, 2011; Driver et al., 2000).

Appropriate means of incorporating critique in science classrooms remain to be clarified and explored. There is a need to characterize the development of critiquing ability among students in science classrooms and to explore possible activities which can engage students in this activity. Here we suggest that inquiry-oriented scientific programs are adequate as a platform for developing students' ability to critique, providing the appropriate support to teachers and the scientific environment.

In this study, we explore the contribution of an inquiry-oriented program for high-school students which emphasizes critique. Our aim is to characterize and evaluate possible changes in students' arguments in response to an arguable claim made by a hypothetical student, focusing on their tendency to agree or disagree with the claim, the number of arguments they use in their answer in response to the claim, the categories of arguments they use and their qualitative characteristics. Our research question is whether participation in an inquiry-oriented program improves high-school biotechnology majors' ability to critique. In order to answer this question, we set to examine whether students who participate in the inquiry-oriented program tend to be in agreement with peer claims, do they use more arguments in response to peer claims and whether they focus their arguments more on the experimental process, methods or chain of inferences.

2. Research design and method

This research was designed to evaluate and characterize possible changes in students' ability to critique following their participation in an inquiry-oriented program in biology termed Bio-Tech program. Pre- and post-questionnaires were administered to 11^{th}-grade biotechnology majors who were either participating or not participating in the Bio-Tech program. The questionnaires included a scientific article and a deliberately arguable hypothetical student's claim.

2.1 Research context

The Bio-Tech program at the Weizmann Institute of Science (hereon referred to as 'the Bio-Tech program') is an optional part (1 credit out of a total of 5 credits) of the Israeli matriculation examinations for biotechnology majors during the 11^{th} grade (Israeli Ministry of Education, 2005). It is based on a visit to a biotechnology laboratory in an industrial or academic facility. The Weizmann Institute began supporting the Bio-Tech program in 2009 and the current research was carried out during the 2011/12 academic year. The Bio-Tech program design originates from the Teacher-Led Outreach Laboratory (TLOL) program that is practiced at the Weizmann Institute (Stolarsky Ben-Nun & Yarden, 2009).

The Bio-Tech program is unique and innovative in the following aspects: the inquiry-based approach allows students to practice high levels of open inquiry, a co-teaching approach is implemented (teaching is performed by the class teacher, a research scientist, and a science educator), and the topic of inquiry is learned using the Adapted Primary Literature (APL) approach with an adapted scientific article. This allows the students to learn up-to-date scientific concepts, practice technologically advanced methods and tools and experience a firsthand encounter with authentic science (Yarden et al., 2001).

The investigated biological systems range from the molecular and genetic level, including proteins and organelles, to the living organism level of bacteria, fungi, yeast, and tissue-cultured cells. Currently, six research groups from the Weizmann Institute and from the Robert H. Smith Faculty of Agriculture, Food and Environment of the Hebrew University are taking part in the Bio-Tech program. The techniques used in this program range from simple observational methods (such as bacterial colony growth on plates, color changes in medium, microscope observation) to the use of highly advanced tools and equipment (such as spectrophotometer, PCR, fluorescence microscope). The protocols are specially designed and adapted to fit the students' cognitive abilities and the time constraints of the program.

The Bio-Tech program is carried out during an entire academic school year. It is comprised of learning the background knowledge using an APL article, a preliminary visit to the research institute where students visit the particular laboratory related to their specific project and perform a series of short experiments in which they acquire key concepts and techniques related to the specific inquiry project, formulating the research questions and planning the main experiments in dyads back in the classroom, performing the experiment in a two days main visit to the research institute and analyze their findings and prepare their research portfolio in a 2-5 months long process back in school with the assistance of the teacher. The final grade of each student is determined based on an oral examination which takes place around the end of the school year, conducted by an external examiner (a biotechnology teacher from another school) and the class teacher.

In the Bio-Tech program, much emphasis is explicitly directed to developing the students' ability to critique and articulate their own knowledge and claims. At the beginning of the program, when students study the APL paper, they are engaged in classroom discussions, led by the teacher, in which they are confronted with the scientific knowledge together with the reasons for using the specific scientific methods and tools. They are expected to understand the scientific content and process by the time they arrive at the research laboratory for their preliminary visit. When formulating their research question and planning the experiment, students are actively engaged in communicating with their peers and their teacher. They learn how to defend and explain their research question and are expected to master all stages of the planned experimental process. During their discussions with the teacher, the scientist and the science educator, students are frequently required to justify what they do, to demonstrate their understanding of the research and to explain their results and analysis. Although this process is long and sometimes frustrating for the students, the class instructors are well trained and experienced in providing adequate support and guidance for the students. In the final part of the program, students write a scientific report in the form of a research article, which is a major part of the research portfolio. In the oral examination, the student is expected to defend his/her work and justify its conclusions, as well as present both content and procedural understanding. Taken together, during the Bio-Tech program, students are given numerous opportunities to develop their ability to critique.

Some specific activities, designed for developing the Bio-Tech students' peer-critique and critique abilities, were incorporated into the program. For example, when dyads of students are working on formulating their research question and hypothesis, they are requested to choose among several research questions that they generate and to present the chosen question to another dyad. The other dyad is expected to review and critique the question according to the teachers' instructions. Following this activity, the original dyad receives their peer-reviewed question and asked to relate and consider the comments and to formulate their final research question to be presented to the teacher for further review and approval

2.2 Population

The research population was comprised of 11th-grade biotechnology majors (16-17 years old). Four classes participating in the Bio-Tech program (the Bio-Tech group) and four classes not participating in this or in any other inquiry-oriented program (the Control group) were chosen. In total, 73 students from the Bio-Tech group and 58 students from the Control group filled in both pre- and post-questionnaires.

2.3 Tools

Pre- and post-questionnaires were designed to investigate students' identification of authentic scientific practices in a popular scientific article ('Alarm sounds over toxic teething rings', The New Scientist, July 14, 1997). After reading the article, students were given an arguable statement from a hypothetical student claiming a specific conclusion regarding the article ("This article *proves* that teething rings hurt babies" emphasis in original). This method was based on the previously published work of Ford (2012).

The article discusses the biological health issue of toxins released from babies' teething rings and its implications on their health. In the article, an experiment that was performed is presented, describing the methods and obtained results. After reading the article, students were asked to answer several open-ended questions designed to evaluate their understanding of the inquiry process presented in the article and to explore their question-asking practice. In one of the questions, students were given the hypothetical student's arguable claim (see above) and asked if they agree or disagree with the claim and why. The claim was deliberately arguable, and students were provoked to critique it from various aspects, such as the certainty and confidence level of the claim, the lack of evidence to support this claim and the flaws in the chain of inferences. The pre-questionnaires were administered at the beginning of the school year, before the selected classes had engaged in the Bio-Tech program. The post-questionnaires were administered at around the same time as the oral exam for the Bio-Tech students at the end of the school year.

2.4 Analysis

Only questionnaires of students who answered both the pre- and post-questionnaires were taken for analysis. Each answer was classified according to the students' agreement or disagreement with the arguable claim and the arguments they used were analyzed and categorized. Initial categories, depicted in a bottom-up process by the first author, were reviewed and validated by the second author and two other science education researchers. The classification of arguments to the different categories was unanimous in over 80% of the cases. The non-agreeable categories and arguments were further discussed until an agreement between the validators was reached regarding the classification of the arguments.

Students' answers were statistically analyzed using Statistical Analysis System (SAS) program for both descriptive statistics and comparing frequencies (Chi-square comparing). Results were statistically analyzed using the Wilcoxon signed-rank test for significant differences (Wilcoxon, 1945) and McNemar's test (Siegel & Castellan, 1988). Agreement or disagreement with the arguable claim was calculated as the percentage of students from the total number of students who answered the questionnaire in each group.

To categorize students' arguments, in-depth analysis of their answers was performed. Students' answers were classified into three main categories: (1) arguments regarding the different stages of the experiment described in the article (the ‘described experiment’ category), excluding arguments relating to the connection between the experimental results and the conclusions, which were classified in the second category, (2) arguments concerning the ‘chain of inferences’, namely the arguments made by the hypothetical student that connect the experimental results and the conclusions, and (3) arguments focusing on other issues presented in the article. The first category of arguments regarding the experiment described in the article was further split into the following three subcategories: (1) general arguments, (2) arguments focusing on the experimental process and protocol, and (3) arguments concerning the experimental conditions. The categories, subcategories and examples are detailed below (Table 1). Students’ arguments in response to the arguable claim were qualitatively classified into the above categories and quantitatively analyzed.

Table 1. Categories of students' arguments regarding the hypothetical student's arguable claim

Category	Subcategories	Examples
1. Described experiment	A. General	*"I agree with the student because the article presents the results of a scientific experiment that proves that teething rings release a toxic substance that damages the baby." (Bio-Tech, #21)*
	B. Experimental process	"*I disagree with the student's opinion because the experiment was only performed once with no control and no repeats.*" (Bio-Tech, #5)
	C. Experimental conditions	*"The conditions under which the experiment was performed do not match the conditions under which babies use the teething rings." (Control, #23)*
2. Chain of inferences		"*I agree with the claim because we really see in the experiment that the rings release huge amounts of dangerous poisons.*" (Control, #5)
3. Other issues in the article		"*I disagree with the student…The article mentions that these substances may cause cancer, but it is not certain.*" (Control, #28)

3. Results

3.1 Students' responses to the arguable claim

To examine the possible changes in students' tendency to critique an arguable claim made by a hypothetical student following their participation in the Bio-Tech program, students' answers to the pre- and post-questionnaires were analyzed and compared to those of the Control group who did not participate in any inquiry-oriented program (Figure 1). No significant differences were found between the Bio-Tech and the Control groups in the pre-questionnaire regarding the percentage of students agreeing or disagreeing with the arguable claim ($p>0.05$).

A decrease in the percentage of students who disagreed with the arguable claim was observed in both the Bio-Tech and Control groups (from 64% to 49% and from 69% to 53%, respectively). This decrease was found to be statistically significant in both groups according to McNemar's test (Bio-Tech chi-square=4.17, $p<0.05$; Control chi-square=4.26, $p<0.05$). This decrease was accompanied by an increase in the percentage of students who agreed with the arguable claim in both groups (Biotech from 30% to 49%, chi-square=7, $p<0.01$; Control from 27% to 40%, chi-square=3.26, $p=0.07$).

A more detailed analysis of the shift from disagreement with the arguable claim in the pre-questionnaire to agreement in the post-questionnaire showed that a high percentage of both the Bio-Tech and Control group students shifted from disagreement to agreement (26% and 17%, respectively) with no significant differences between the two groups.

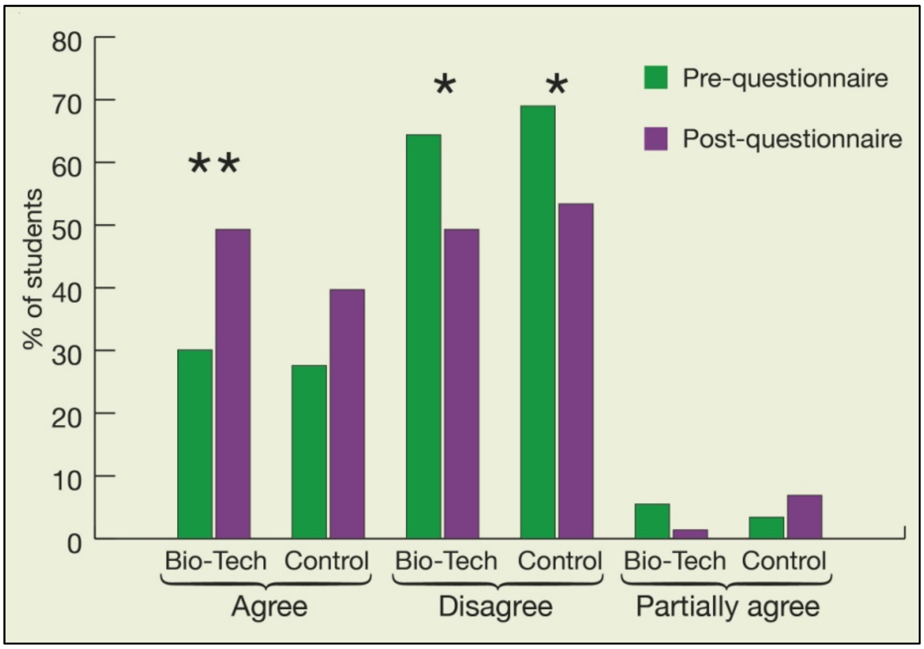

Figure 1. Comparison of students' positions toward the arguable claim in pre- and post-questionnaires (Bio-Tech n=73, Control n=58, *p<0.05, **p<0.01).

An example of students' tendency to shift from disagreement to agreement with the arguable claim, seen in both the Bio-Tech and Control groups, can be found in the analysis of one of the student's answers. This Bio-Tech group student (#55) disagreed with the arguable claim in his pre-questionnaire answer, using arguments related to the chain of inferences (*"I disagree with the student since this article didn't prove that all of the teething rings are dangerous for babies. It proved that there are specific kinds of teething rings that release phthalates and are dangerous for use, but that there are other teething rings which are not considered dangerous."*). In the post-questionnaire, the same student changed his opinion, agreeing with the claim and using arguments related to the experiment described in the article (*"I agree with the student since after establishing the hypothesis, the researchers performed the experiment in order to prove their hypothesis and with the experiment they proved that teething rings are dangerous for babies because of the phthalates that are released from them").*

In summary, students of both the Bio-Tech group and the Control group tended to be more in agreement with the arguable claim in the post-questionnaire, indicating that participation in the Bio-Tech program did not make the students more opposed to or less likely to agree with a peer's claim.

3.2 The number of arguments used by the students

We then explored possible changes in the number of arguments used by students in their answers following participation in the Bio-Tech program. We assumed that an increase in the average number of arguments might indicate a possible change in the students' ability to critique. However, no significant differences were found in the average number of arguments used by the Bio-Tech group students in the pre- and post-questionnaires (1.69 and 1.67, respectively, Figure 2). On the other hand, a statistically significant ($p<0.05$) decrease in the average number of arguments was found among students of the Control group (1.84 and 1.39, respectively, Figure 2). This indicates that the ability to use arguments was retained by the Bio-Tech students, while this ability showed a regression among students who did not participate in the inquiry-oriented program.

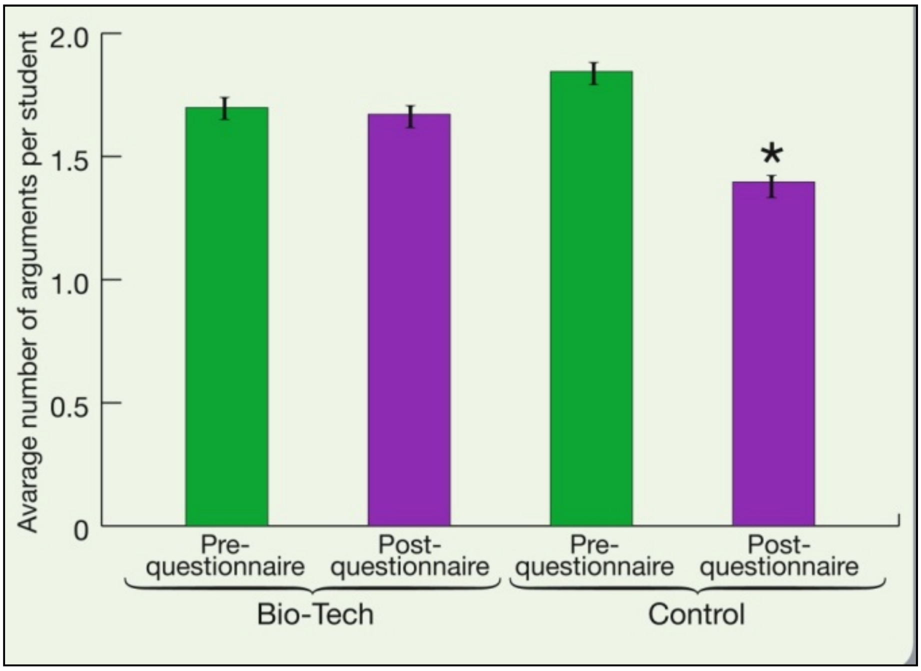

Figure 2. Average number of student arguments in pre- and post-questionnaires (Bio-Tech n=73, Control n=58, *$p<0.05$).

An example of the decreased average number of arguments in the answers of Control group students is presented in the following quote. This student (#55) from the Control group, who did not participate in the Bio-Tech program, disagreed with the arguable claim in the pre-questionnaire, using three arguments from the category of 'chain of inferences' ("*I disagree with the student, since the experiment in the article was performed on only 11 types of teething rings and this is not enough to determine and generalize that all teething rings are dangerous. There may be other companies that are not using this substance*"). In her post-questionnaire, however, this student agreed with the arguable claim and used only one argument in her answer ("*I agree. The article shows an experiment that proves that the teething rings are dangerous*").

3.3 In-depth analysis of students' arguments

To further explore the students' arguments and understand the possible changes in their arguments before and after the intervention, an in-depth investigation of the type of arguments used by the students was carried out. Students' answers were classified into categories and subcategories, as detailed in the methods section.

Classification of the students’ arguments revealed that most of them, in both the Bio-Tech and Control groups, focused on the chain of inferences in both pre- and post-questionnaires

(Figure 3). There was a significantly (p<0.005) higher percentage of arguments related to the experiment described in the article in the pre-questionnaires compared to the post-questionnaires among the Bio-Tech group (from 10.6% to 25.6%), while no statistically significant change was observed among the Control group students according to Wilcoxon test.

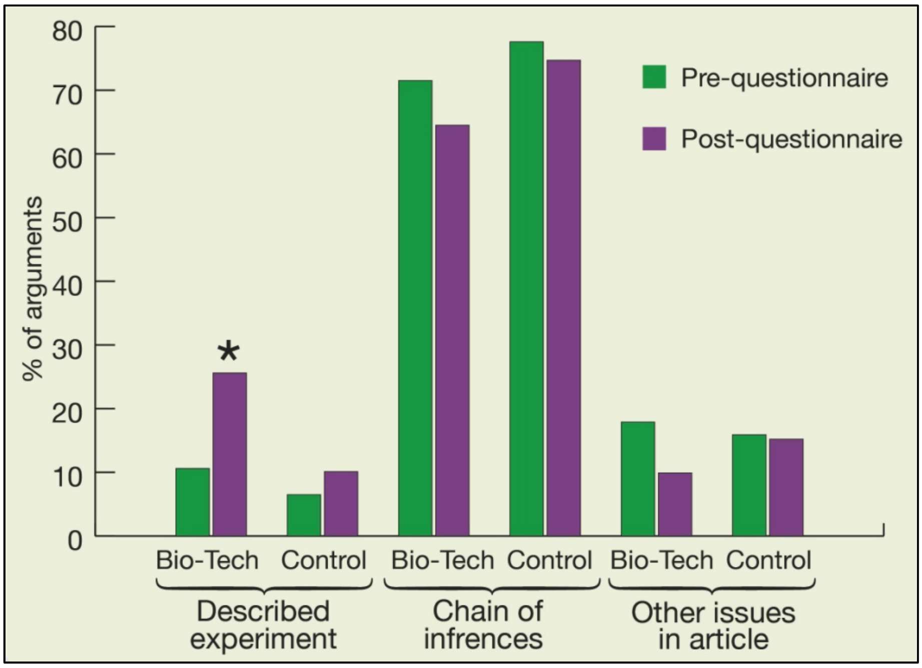

Figure 3. Comparison of students' argument types in pre- and post-questionnaires (Bio-Tech pre n=124, Bio-Tech post n=122, Control pre n=107, Control post n=81, *p<0.005).

An example of the increased tendency of Bio-Tech students to use arguments relating to the experiment described in the article is presented here. One of the students (#27) from the Bio-Tech group wrote an answer in the pre-questionnaire which included an argument from the category of other issues in the article, specifically arguments concerning the health issues of babies who use teething rings (*"I don't agree with the student. It was not experimentally examined or written in the article if phthalates are dangerous for babies or how they affect them. Maybe babies have immunity to phthalates? They didn't examine the activity of the baby who uses the teething rings compared to a baby who does not, therefore you can't know if the teething rings are dangerous."*). In the post-questionnaire, however, the same student still disagreed with the arguable claim but used arguments from the category of the chain of inferences (*"I disagree. The third ring released only 9 mg of phthalates and this amount is small and harmless")*. In addition, he used an argument from the category of the described experiment ("*They need to repeat the experiment to validate the results, examine all kinds of rings and only then determine which rings are dangerous")*.

A closer examination of the total number of arguments used by the Bio-Tech students that are related to the category of the described experiment (Figure 4) revealed an increase in the post-questionnaires in all three subcategories: general issues of the experiment (from 2 arguments in the pre-questionnaire to 7 in the post-questionnaire), the experimental process (from 8 arguments in the pre-questionnaire to 17 in the post-questionnaire) and the experimental conditions (from 3 arguments in the pre-questionnaire to 7 in the post-questionnaire). This indicates improvement in the Bio-Tech students' ability to critique all aspects of the experiment presented to them.

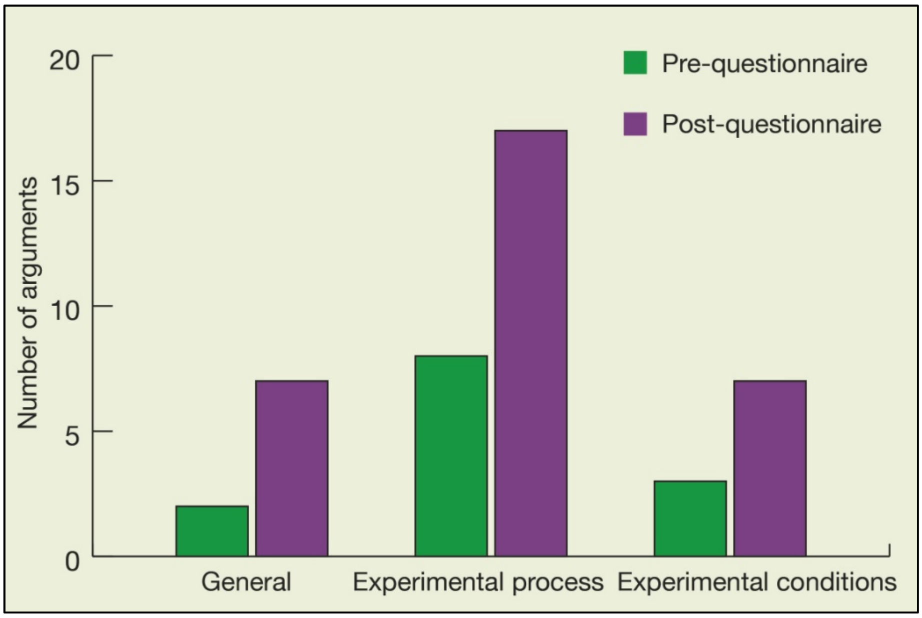

Figure 4. Number of Bio-Tech students' arguments related to the experiment described in the article (Bio-Tech, n=73).

Altogether, the results show that even though the overall tendency of the Bio-Tech students to disagree with the arguable claim does not increase following their participation in the Bio-Tech program compared to Control students, the former were better able to use arguments, and the number of arguments that focused on the experiment described in the article increased among the Bio-Tech students. The qualitative analysis supports the observed change in the type of arguments used by the Bio-Tech students before and after the intervention.

4. Discussion

Experiencing inquiry and gaining an appreciation of authentic scientific practices are key elements of science learning and teaching (National Research Council [NRC], 2012). The ability to critique is crucial in students' development of skills, abilities and understanding of scientific discourse and habits of mind (Berland & Reiser, 2009; Ford, 2008). In the study described herein, we explored possible development of students' ability to critique following their participation in the inquiry-oriented Bio-Tech program. No differences were observed in students' tendency to disagree with an arguable claim that was presented to them following the intervention between the Bio-Tech group and the Control group. Students from both groups appeared to be more in agreement with the arguable claim. This indicates that participation in the Bio-Tech program does not affect the students' ability to disagree more with an arguable claim. It may imply that developing students' ability to dispute and reject peer claims requires deeper and more explicit learning of critiquing. However, we found that participation in the Bio-Tech program leads to some improvement in students' ability to critique, mostly in their tendency to use more arguments and to critique experiments presented to them. Following participation in the program, the average number of arguments used in the pre- and post-questionnaires was sustained among the Bio-Tech group, in comparison to the Control group in which a significant decrease in the number of arguments used was observed in the post-questionnaires. This indicates that participation in the Bio-Tech program may have supported the students' argumentation and critiquing abilities.

The decrease in the average number of arguments used by the Control group might be explained by the fact that they were already familiar with the article presented in the questionnaire and they refrained from seriously engaging in answering the questionnaire. This may indicate that the ability and dedication of the Bio-Tech students to engage in critique about a topic that was already introduced in earlier experience have improved.

Furthermore, students of the Bio-Tech program tended to focus more on the experiment that was described in the article in their answers. This indicates that the Bio-Tech students improved some of their ability to critique and implies the possible development of this ability following participation in the Bio-Tech program.

Our results partially correlate with those presented by Ford (2012), who showed that students who focus on learning to critique while practicing an inquiry-oriented scientific activity improve their peer-review practice and their reasoning and argumentation abilities. The Bio-Tech students demonstrated development of their ability to critique, mostly enhancing the number of arguments used and the use of arguments related to the experimental process and method compared to the Control group. It should be noted that the Bio-Tech students' tendency to disagree with an arguable claim did not increase compared to students from the Control group, unlike the students who participated in Ford's Research (Ford, 2012).

Further research and analysis is required for a full understanding and appreciation of the development of students' ability to critique in the course of participation in inquiry-oriented programs. Deeper examination of the development of the ability to critique by inquiry-oriented students is required, due the relatively small number of students who participated in this research and the limited number of differences between the groups that were found. Our aim is to further analyze the development of students' ability to critique, to explore the students' long-term learning of critiquing and other abilities of the authentic scientific practice and to examine the learning of these abilities in other inquiry-oriented programs. We also plan to further and more deeply explore the development of students' ability to critique while participating in the Bio-Tech program, focusing on their ability to critique their own and their peers' research processes.

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10 COMPARATIVE ANALYSIS OF THE ACTIVITY OF TWO TEACHERS IN TERMS OF PUPIL'S ACCULTURATION TO SCIENCE

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Abstract

French curriculum places great emphasis on problem-based learning because scientific problems are supposed to have an essential part in the construction of scientific concepts. For researchers in didactics, the students' appropriation of scientific problems is necessary to allow them to start assimilating scientific culture and to build knowledge.

In this paper, we study how two teachers (a student and an experienced teacher) conduct a phase of problem building involved in acculturation to science.

In the analysis of the teachers' actions during those sessions, we identified two kinds of sequences: times of convergence and times of divergence. During the phases of convergence, the teacher's actions (through problems building and solving) engage students in a process of acculturation to scientific ways of knowing, whereas during the phases of divergence, the teacher's actions, even if they stick to the topic, don't support this process but aim to fulfill other requirements of school teaching. We found that the occasions of convergence were more numerous in the session led by the inexperienced teacher, while those of divergence were more common in the session led by the experienced teacher. Our study tries to identify the differences between the two teachers and to explain their source.

Keywords: Acculturation to science, professional gestures, language interactions, problem-based learning

1. Introduction

The renovation of the teaching of science has led to the promotion of a form of science education based on the scientific inquiry model. It is important to realize that scientific problems differ from everyday ones. The process of scientific inquiry, as described in the French curriculum, places great emphasis on those scientific problems because they are supposed to have an essential part in the construction of scientific concepts. For researchers in didactics, the students' appropriation of scientific problems is necessary to allow them to start assimilating scientific culture and to build knowledge.

In the following article, we study how teachers can take into account this consideration, particularly in debates proposed to students.

For this purpose, we compare the actions of two teachers, an inexperienced teacher (a student in the second year of her postgraduate master's degree) and an experienced teacher, when conducting a phase of problem building during a scientific debate. The aim of this study is not to compare their respective skills, but to show how they allow students to construct the involved knowledge and then to identify the professional practices that facilitate the construction of knowledge in science teaching.

2. Theoretical framework

Our study uses a double theoretical framework

- The rationalist tradition of science education, which considers that there is an epistemological rupture between everyday knowledge and scientific knowledge (Bachelard, 1938; Canguilhem, 1965; Popper, 1972) ;
- The socio-historical approach to learning, which considers that schooling should allow students to acquire the knowledge that is specific to scientific culture and ways of thinking, talking and doing associated with that knowledge (Vygotsky, 1986; Brossard, 2004).

The rationalist tradition of scientific activity emphasizes the importance of to the construction of scientific problems, rather than their resolution and thus their solution (Bachelard, 1938: "*the meaning of the problem is the true mark of the scientific spirit*"). This leads us to examines how speech acts of the teacher do or don't enable students to appropriate scientific problems involved in the situations they set forth. Through the analysis of the practice of each teacher, we try to understand how they manage the construction work of the problem by the students.

Members of the scientific community share very specific ways of thinking, talking and doing with which the knowledge constructed by the scientific community is very deeply connected.
According to our theoretical framework (socio-historical approach to learning), we consider that schooling should allow students to acquire not only this knowledge but also these ways of thinking, talking and doing. We call acculturation the process by which students are introduced to this culture.

Our previous studies have shown that students' appropriation of scientific problems is necessary to start assimilating scientific culture and to build knowledge. In a social perspective on learning, the challenge lies in helping learners to achieve this process of acculturation successfully in the classroom. According to Driver and al. (1994), the teacher's intervention is essential.

3. Key objectives

Our purpose is to understand, thanks to a comparative method, how two teachers, whose experience is very different, go about facilitating the construction of a scientific problem by the pupils so as to engage them in a process of acculturation to science.

One of them, inexperienced, had very recently been studying the teaching and learning of Natural Science and so, before constructing the session focused on nutrition, she had already conducted a reflective work in didactics. The session carried out by that novice teacher was then analyzed with her supervisor in order to write her master's assignment. The other one, an experienced teacher, had implemented a similar session, which had been prepared by the inexperienced teacher.

We will try to associate the results of our analysis in respect of the experience of each teacher.

Our research questions are the following:

1. How and why a teacher's actions do or do not enable students to appropriate scientific ways of knowing?
2. Which actions promote the construction of a scientific problem in the classroom and what those which delay it?

4. Research design and method

4.1 The educational project

Both sessions took place in two primary school classes (10 year-old pupils).

The starting point of the session was: *"How does the grass eaten by the rabbit enable it to form bones, muscles, etc?".* The pupils had to complete a drawing (Figure 1) and indicate the connection between the physical development of a rabbit and the food it eats. Then a debate took place, using the comparisons of the posters produces by the working groups.

The proposed situation potentially contains the problem of distribution because the drawing shows the distance between the digestive tract (where the food goes after eating) and the organs which grow (muscles, bones)

On the topic of nutrition, we can identify two–categories of recurrent problems that arise in different forms and different formulations according to educational levels:

- The first problems concern the issues of absorption and of distribution: foods or nutrients have to leave, one way or another, the digestive tract to reach different parts of the body.
- The second ones concern the problem of assimilation: how can living beings produce their own material from what they gather from the surroundings? Both issues are present in the primary, middle and high school curriculums.

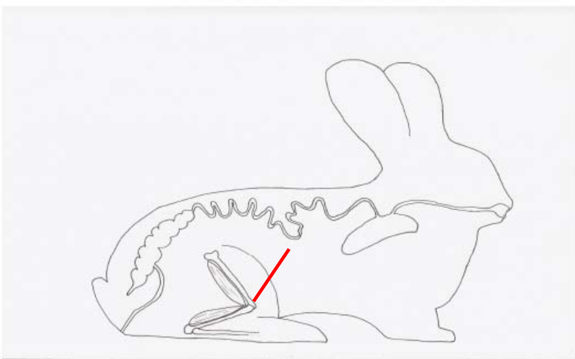


Figure 1. The drawing pupils have to complete.

The red line between the digestive track and the bone of the leg didn't appear on the drawing that the students had to complete; it had been added here in order to show the distance between the two parts of the rabbit which have to be somehow joined for a comprehension of the function of nutrition.

Students have to understand the need of a distribution of nutrients to fill the gap that exists in the diagram between the digestive tract (represented by a pipe without holes) and organs.

4.2 Corpus

Both teachers have been voluntarily chosen because of the contrasts in terms of their professional experience and their working conditions. The inexperienced teacher designed the session as part of its research work (for her MASTER assignment) on the problem building in science. During her training, she studied the concept of problematization through many articles. She implemented her device in a class of 24 students during an internship included in her training (3 weeks).The experienced teacher implemented the device from the elements of preparation of the student who had also provided research articles on the subject (Lhoste & Peterfalvi, 2009). The sequence took place in his class year (19 students). We observed the teachers' speech acts.

We collected data in the two classes during the first four sessions of the sequence on animal nutrition:

- a diagnostic evaluation session;
- a working session in homogeneous groups (students with similar representations) where they were asked to produce a poster (same task as the one proposed in the diagnostic evaluation);
- two sessions of scientific debate.

The following sessions (working on documents and conclusion) have not resulted in a collection of data in light of our research questions.

The corpus is composed of different materials:

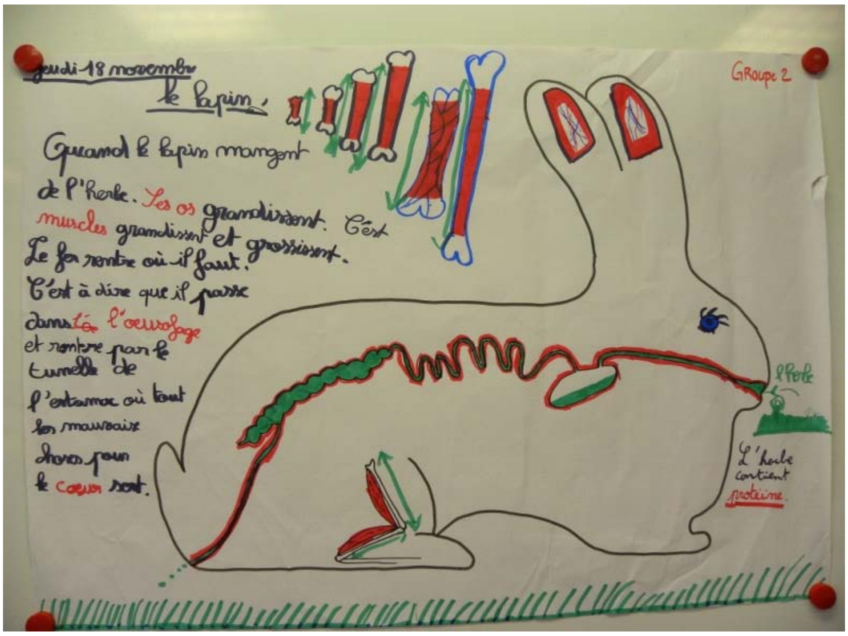
- The preparatory document for the session which is aimed at the appropriation of scientific problems by the students, made by the inexperienced teacher and then used by both the inexperienced teacher and the experienced one to implement a similar session.
- All the written work of students, posters produced by the working groups (Figure 2) and class posters.
- Transcripts of the video recordings of the 2 sessions.

The preparatory document for the session

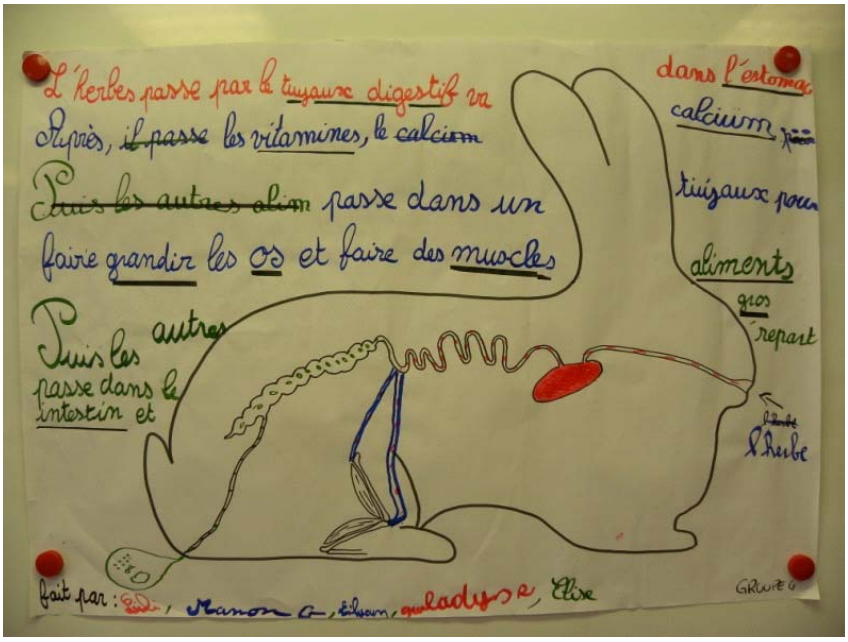
We can already notice some ambiguities or implicit contents inside this document, which can explain that the experienced teacher didn't always understand the aim of what the inexperienced one planned to achieve in the session. The inexperienced teacher tried to anticipate the obstacles to be overcome to help pupils understand nutrition (Clément, 1991). However, the obstacle corresponding to the idea of a sealed pipe representing the digestive tract is not clearly expressed in this document (Clément, 1991). Therefore, while the novice teacher focused the debate on the issue of absorption, the experienced teacher obviously did not take the importance of the work on this obstacle into account.

Table 1. Excerpt of the preparatory document

Study Theme	**Nutrition**
The object of study	Supplying organs with nutrients that can enable the production of matter specific to the individual
The problem studied	The production of material from the supply
Obstacles	The body is a closed bag - Existence of two pipes, one for the liquid and the other for the material - Foods remain trapped in a sealed tube - "What is good or bad" - circulation of blood: unclosed circuit
Proficiency in its productive dimension: the performance objective	Students should be able to: - report the transit of the food (specific) in the digestive tract and their transformation into non-specific nutrients - Explain that nutrients must be absorbed in order to pass into the blood - Explain the distribution of these nutrients throughout the body via a closed circuit
Competence in its constructive dimension: the goal of transformation	Transformation of the food into a nutrient through a mechanical action in connection with a chemical action to change its specific nature into a nonspecific one, the mechanical action facilitating the chemical action - specific and characteristic wall, notion of sorting out: processed and unprocessed - Exchange surface with the blood, moving from the idea of a pipe to the idea of a closed circuit
Learning content or the conditions of transformation	Awareness of the need for assimilation to develop, hence a need for distribution, absorption made possible through the food processing through mechanical and chemical action.



When the rabbit eats grass, its bones get bigger, its muscles grow and get bigger. The iron enters where it has to. I.e. it passes through the esophagus and enters through the tunnel of the stomach where all the bad things for the heart go out.



The grass passes by the digestive pipe, goes into the stomach. After ~~it passes~~ the vitamins, calcium,...
~~And the other food~~ passes through a pipe to make bones grow and make muscles. And the other food passes into the large intestine and goes out.

Figure 2. Examples of drawings produced by two of the working groups.

4.3 Methods

We made a microscopic analysis (of each student's proposal) to show the construction of knowledge in relation to our epistemological analysis (*a priori* analysis which allows us to identify: ingredients of the object of knowledge, relationships between these ingredients etc…). Then we analyzed the teachers' linguistic action that prompted the students' proposals.

Divergence and convergence are defined by the following features :

- Convergence refers to the trace of the construction of the object of knowledge by students. The teacher' interventions help the construction of the object of knowledge.
- Divergence refers to the trace of the construction of the object of knowledge by students. The teacher' interventions of are not in line with the continuation of this construction.

Then, we categorized the teacher's speech acts during the moments of convergence and divergence.

In order to identify how pupils engage in a process of acculturation to science from the viewpoint above-mentionned, we analyzed the transcripts of the 2 sessions, using a didactical analysis combining two approaches, focused on linguistics and on the construction of scientific problems (Lhoste 2008; Lhoste & Schneeberger, 2009; Schneeberger & Vérin, 2009).
We analyzed the specific actions of each teacher that enabled this process to be initiated.

5. Examples of our analyzes

In the analysis of the teachers' actions during those sessions, we identified two kinds of sequences: times of convergence and times of divergence. During the convergence phases, the teacher's actions focus on the process of problem building, whereas during the divergence phases, the teacher's actions, even if they stick to the point, express a tension between this aim and other concerns.

5.1 Two moments of convergence

Script 1 below deals with the problems of the distribution and absorption of nutrients.

The analysis of the debate transcript shows how pupils engage in identifying the problem thanks to their teacher's help.

In 37 ("*So the mixture goes into the blood*?"), the teacher selects from Manon's proposition (her explanatory model, her "solution"?) something that focuses the pupil's discussion on the problem of distribution. That discussion could potentially start working about the obstacle. In 42 (Elise: *And how will the vitamins go to the muscles and bones?)*, we can observe the first identification of the scientific problem by the pupils. Elise is proposing a sort of formulation of the problem of distribution / absorption, but she doesn't give the reason why that is a problem: a priori, it is not plausible because we don't see how it would be possible to go through the intestine.

In 43 (the key moment on which we now focus our attention), the teacher repeats that formulation and writes it on the blackboard. That professional act (writing a sentence proposed by a pupil on the blackboard) is in keeping with the progress of the pupils by identifying the problem, but in a special way. What is written is a question. It changes the status of this question, which becomes a question to be solved by the whole class. This common professional gesture supports the specific process of construction of the problem of distribution / absorption which is now clear for the whole class. That constitutes an example of what we call “convergence”. During that exchange, and in what follows, we can see how pupils gradually identify the problem of distribution / absorption that was potentially indicated in the starting situation (the digestive tract is away from the organs).

Script 1. A moment of convergence (inexperienced teacher).

36 – Manon*: Actually, when the rabbit eats, the blood flows up around the ears so that the mixture well,... it goes into the blood*
37 – Teacher: *So the mixture goes into the blood?*
38 – Manon: *Well, actually it's the grass that goes into the body, it eats grass and then crushes it (the grass).*
39 – Teacher: *Okay that makes a mixture and the mixture goes into the blood.*
40 – Manon: *That's it.*
41 – Teacher: *Other questions?*
42 – Elise: *And how will the vitamins go to the muscles and bones?*
43 – Teacher (writing on the board): *How will the vitamins go to the skin and muscles?*
44 – Manon: *Well, you you take orange juice in the morning, ah you don’t, there are vitamins in fruit, and stuff, there are vitamins. And inside... there is a kind of little product and it makes the rabbit develop.*
45 – A pupil: *The root.*
46 – Manon: *Yes.*
47 – Lili: *What did you draw for it to make the bones grow, because…*
48 – Davy: *Yeah, we can’t see very well.*
49 – Manon doesn’t answer.
50 – xxx (inaudible)
51 – Teacher: *In fact what Lili is asking you, is what makes the rabbit grow if the grass is here and it grows there.* (She shows the intestines of the rabbit and the place of muscles and bones).
52 – *Manon: is mulling it over but does not answer*
53 – Teacher: *There was no answer. She shows their explanation. But it does not matter we cannot answer all at once.*
54 – A pupil*: If this is the mixture that passes through the gut, how come everything passes in the blood like that?*
55 – Teacher: *Yeah, well that's the question that they did not answer in their poster. We will try to see with the second group if they provide an explanation. We will write your question and you’ll try to reformulate it.*
56 – Bryan: *How can a big mixture pass through the organ like that?*
57 – Luci: *How does the mixture go into the blood?*

So, by this convergent act, the teacher entered a formulation of the problem to provide a starting point for further research).

Gradually the problem is made more precise and takes on the collective status of a problem to be solved. In 47 (student: "*What did you draw for it to make the bones grow, because...");* 51 (teacher: "In fact what Lili is asking you, is what makes the rabbit grow if the grass is here and it grows there". She shows the intestines of the rabbit and the place of muscles and bones) in 53 (teacher: "there was no answer"); in 54 (pupil:" *If this is the mixture that passes through the gut, how it is that everything passes in the blood like that?*"); in 55 (teacher: "this is the problem to which we don't have an answer yet"); in 56 and 57 (pupils reformulate the problem as a puzzle taking the sieve as a model to solve it). The general professional gesture (writing a pupil's sentence on the board) had as effective consequence to allow pupils to specify the problem to be solved.

Thus, in this sequence, the observed convergence has a double effect: the precision of the problem's formulation, and shared by at least the 7 pupils who speak in this short exchange.

Script 2. A moment of convergence (experienced teacher).

382 – Student: *When we grow up, the spine grows too. So when the rabbit grows up, its spine will get longer. That's why we drew a spine.* 383 – Teacher: *On your drawing did you explain how the spine grows?* 384 – Student: *In fact when you eat, the spine grows along with it because there is a kind of food, let's say it like that, which makes it grow* 385 – Teacher: *How does the food make it grow?*

In 382, a pupil focuses on the growth of the body to explain why he drew the spine: when the spine grows, the body grows too.

In 383, the teacher focuses the theme (382) on the problem of growth.

In 384, the student initiates the construction of the concept by setting temporary relationships between the food entering the body and its growth. Such a link allows the idea of distribution to be built (how the "*kind of food*" makes it grow) in connection with the ideas of transformation and sorting out envisaged earlier ("a sort of"), because it is not what you eat but something a little different that makes its bones grow.

In 385, the teacher resumes the questioning about the problem of growth (after 383). We explain this intervention to be a sort of recovery-change from "*food*" to "*kind of food*".

We consider that her interventions 383-384 act as inductors for the position of the problem (Schneeberger & Lhoste, 2010; Lhoste, Peterfalvi & Schneeberger, 2010). Her questions initiate an explanation from pupils and arise from a solution proposed by pupils to a condition of the problem (it is necessary to make the bones grow).

Furthermore, we analyze this extract from the point of view of the construction of a discursive community applied to science education (Bernié, 2002).

In 382, the pupil's speech is relatively general ("*we*") instead of using the specific example studied here. The pupil tries to give an explanation whereas his formulation still shows a tension between an explanation ("*therefore*", "*that's why*") and a plain narrative ("*when*" ... "*when*").

In 383, the teacher takes up the intervention 382 of the pupil and focuses on the explanatory dimension of the task: "*Did you explain how?"*.

In 384, the pupil goes on to trying to explain although the explanatory dimension is still a logical chronology.

5.2 Examples of divergence

5.2.1 The development of each pupil (experienced teacher)

Script 3.

22 – Doriane: *How does the rabbit grow?*
23 – Julie: *I do not know*.
24 – Marouan: *Well it's written here*.
25 –Teacher: *You're right Doriane. I could have asked the question too. He has explained the transit of the carrot but he doesn't really explain how the rabbit develops. Any questions?*

In 25, after having highlighted the interest of the answer to the pupil's question which pointed out a problem with the development of the rabbit, the experienced teacher quickly opened the discussion to other pupils ("any questions?"). Although there was an opportunity to focus the pupils' attention on a relevant issue to help them get into a scientific reasoning (e.g. by shifting to writing on the board, as in the previous example), the teacher gave the floor to the class.

We interpret that episode as being divergent; this type of intervention is very common with the experienced teacher. It seems that this is a professional gesture of educational nature which expresses the desire to allow the greatest number of pupils to express themselves and to prize all pupils, but the pupils ended up by not understanding the real sense of the scientific problem. Thus, there is a discrepancy between the pedagogical concerns and maintaining the process of acculturation.

5.2.2 The logic of "labeling" (experienced teacher)

Script 4.

42 – Teacher: *They described all the transit of the carrot inside the body, it goes out, this means that it came in. Any questions?*
43 – Julie : *Marla*
44 – Marla: *Why did you speak of cells when you do not know what they are?*
45 – Julie: *Well actually …*
46 – Teacher: *Where does it come from, that word, where did you find it?*
47 – Julie: *Actually Andrea wrote it.*
48 – Teacher: *Andrea you should know it because you must have heard it somewhere. Yes*
49 – Anthon: *Cells are in the brain.*
50 – Pupil: *And in the blood too.*
51 – Anthon: *Also in the blood with red blood cells*.
52 – Teacher: *Why do the girls have this word in mind? Marouan.*
53 – Marouan: *Because of Gulli*, there is a cartoon that talks about that.*
54 – Teacher: *Is it true that this word comes from Gulli*?*
55 – Pupil: *Yeah, it was "once upon a time in our body.*
56 – Teacher: *Ok, good. Other questions?*

*a TV Channel

We interpret the different interventions of the teacher highlighted in grey as times of divergence. In fact he gets to a professional routine (defining all the words used by pupils) even if the pupils' requests lead them away from the scientific issue at stake in the session. We can notice that this divergence belongs to a different category from the first one. While in the first example the divergence came from a conflict between the purpose of encouraging the problem building and the wish to involve everybody in the debate, here the divergence springs from two antagonistic conceptions of science itself: one in which problem building is considered as crucial, the other one in which the words and their meaning must be clarified before. So the discrepancy is more epistemological.

6. Results

In these examples we can see that some actions of the teacher, regularly found in school teaching (such as writing a question on the board), have some general aim so as to involve all the pupils of the class in the activity in progress, whereas other actions focus specifically on the problem's formulation and building. Sometimes, these two categories of actions can support each other, while some other times, they can be antagonistic

We identified times of divergence and convergence with both the novice teacher and the experienced teacher. However, the moments of convergence are more common with the inexperienced teacher than with the experienced teacher. Times of divergence are (three times) more frequent with the experienced teacher. In the class of the experienced teacher, all the moments of convergence happen at the end of the debate (371-433).

From our analyses, we can distinguish which actions promote the construction of a scientific problem in the classroom and what those which delay it. However even if one of the teachers (the inexperienced one) was more focused on the problem building than her colleague, her task is not free of tensions and requires choices which sometimes makes her deviate from ongoing important reasonings.

These kinds of tensions must be taken account to better understand how a teacher adjust his actions while allowing the students to appropriate scientific ways of knowing.

7. Discussion

Our initial analysis, which is limited to a single case, even if two different ways of teaching have been studied, allows us to identify the fact that some professional teachers' common actions could be in either convergence or divergence with the process acculturation to science In the case of the experienced teacher, the professional acts that correspond to regular routine, even if connected with « socio-constructivist » practices, such as group learning and debates, are often in divergence with the construction of the concept studied (Bautier & Rayou, 2009). In the case of the inexperienced teacher, moments of convergence are more frequent.

We make the following hypothesis to interpret the difference between the two teachers: the task of preparing the session in connection with the requirements of her master's degree assignment, compelled the young teacher to identify the scientific problems to build accurately when studying this topic (animal nutrition), to take into account the articulations between them and to anticipate the obstacles to be overcome. The construction of the situation by the inexperienced teacher in connection with the training analysis also seems a favorable element.

The professional acts of the teachers could explain the divergence with the scientific acculturation process of pupils.

The observed difference may also be connected with the fact that the experienced teacher has the whole responsibility of his class, and therefore, has to take into account many more constraints than those directly connected with this specific problem. The inexperienced teacher is in charge of that sequence only, she doesn't know all the pupils very well, she is in a much more protected situation. Because of this, she doesn't have to cope with the professional conflicts the experienced one does. This is a very important fact to take into account, because it can directly influence the success or the failure of this kind of teaching.

Our results are only preliminary and need further investigation: interviews to support our initial analysis and, above all, other types of comparison. We suggest that teacher training does not consist in simply giving teachers a bank of problem situations they just have to implement, or in teaching them directories of professional actions, but to give them a consistent didactic culture so that their action is geared to the acculturation process in science.

These are suggestions, not requirements or recipes.

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11 CONTENT CHOICES WITHIN A CONCEPT-CONTEXT APPROACH IN PRIMARY SCIENCE EDUCATION

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Abstract

Trends in Dutch biology education have recently led to the development of a conceptual framework for primary science education in which a concept-context approach holds a central position. This study describes how choices can be made in the selection of concepts from the framework for curriculum inclusion with a focus on the concept animal. Its aim is to arrive at an elaboration of this concept in terms of underlying and related concepts. Especially guidelines were collected to justify these choices. Therefore, primary teacher educators for science education and primary school pupils were interviewed. Alongside, an analysis of methods for primary science education was carried out and experts were asked to fill in a questionnaire. This resulted in appropriate guidelines, underlying concepts and/or everyday life contexts interesting for pupils. With these outcomes two example elaborations for different age categories were made and subsequently presented, along with the guidelines found, to experts during a focus group discussion. Ultimately, the findings revealed three criteria (context, subject and didactics) to be taken into account when selecting concepts. To elaborate the concept animal the suggested procedure can be used, in which the interaction between selecting concepts and contexts is central.

1. Introduction

The concept-context approach was recently introduced in Dutch biology education to achieve coherent biology education from primary education to secondary education (Boersma, Kamp, Van den Oever, & Schalk, 2010). The concept-context approach takes the learner as its starting point and requires that the education on offer is meaningful for children (Van Graft, Boersma, Goedhart, Van Oers, & De Vries, 2009). In the concept-context approach contexts, activities and concepts are connected in a specific way. Contexts are defined as practices such as farming, cooking or investigating (Boersma et al., 2005). Several types of contexts are distinguished, including everyday life contexts (Boersma et al., 2005; Boersma et al., 2007). Everyday life contexts, like health care or family, are especially relevant for pupils in primary education, because in these practices children (potentially) participate (Van Graft et al., 2009). Within these practices specific activities are performed which ask for specific biological knowledge to be associated with one or multiple biological concepts. A concept is defined as “an important idea from biology with which relevant knowledge could be associated” (Boersma et al., 2005, p. 15).

A first step to translate the concept-context approach to primary education was the development of a conceptual framework. This framework provides an overview of combinations of everyday life contexts and 23 biological concepts for further application in primary science education (Van Graft et al., 2009). This study describes how choices can be made in the selection of concepts from the framework for curriculum inclusion and which guidelines can be followed to justify the inclusion in the curriculum of some concepts over others. Guidelines are therefore defined as arguments that support choices for content and concepts. Ultimately, this step of making choices could be the start of the development of a curricular strand for primary science education. In particular, the concept animal, one of the concepts making up the conceptual framework, is focused on in this paper. The research study aims to arrive at an elaboration of the concept animal in terms of relevant, underlying and related concepts for primary science education. Furthermore, the essence of the study is in collecting guidelines which support choices for specific content and concepts about the concept animal. The following research question was formulated: How can the concept animal be elaborated in Dutch primary science education according to the characteristics of the concept-context approach and which guidelines can be found to support this elaboration?

2. Research design and method

The qualitative research study is part of curriculum development and followed the communicative approach. This approach pursues a relational strategy where stakeholders play an important role. Their views and opinions about making choices for a curriculum can be identified in a consultation aiming to reach consensus (Thijs & Van den Akker, 2009). The method consisted of several components (Figure 1). First, guidelines which support choices for content and concepts, underlying concepts related to the concept animal, and everyday life contexts interesting for primary school pupils, were identified. As far as possible, guidelines were selected on generality, so that they were applicable to multiple concepts related to the concept animal.

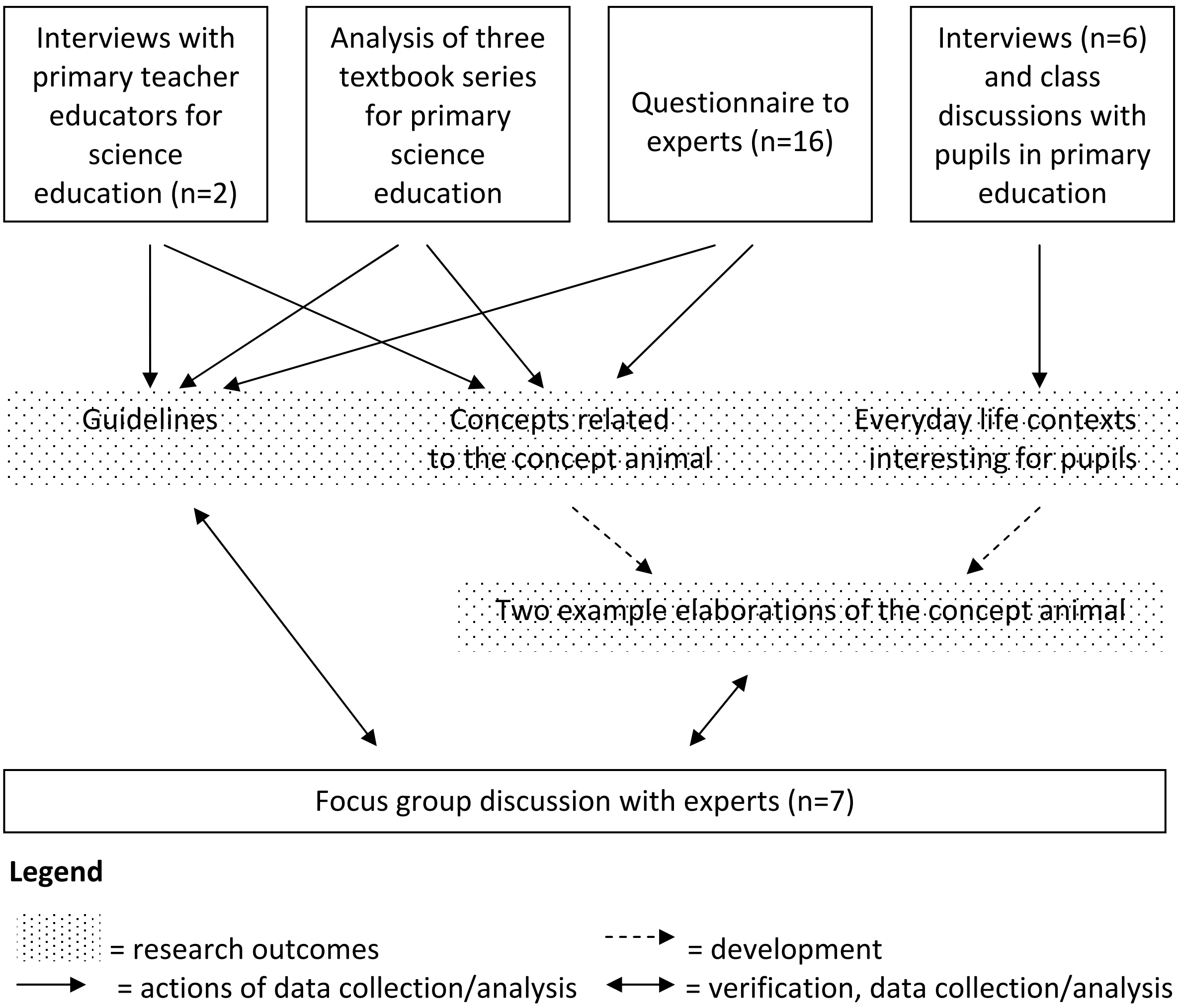

Figure 1. Schematic overview of the research method.

Developing an elaboration of the concept animal according to the concept-context approach, the aim of the study, requires working within an everyday life context. These everyday life contexts were selected from the results of the interviews and class discussions with pupils in primary education. An elaboration was made for children in the age of 4-8 years as well as for those aged 9-12 years, resulting in two example elaborations. The elaborations were defined as underlying concepts that can be connected to the concept animal, and were derived from other components of the research method. A concept was selected for inclusion in the elaboration when it met the criterion that it applied to the chosen context or was considered important by experts and primary teacher educators. Subsequently, the guidelines found for selecting concepts and the two elaborations were presented to experts during a focus group discussion. This approach investigated whether the elaborations and the guidelines were appropriate. For this study a 'policy' Delphi study was followed to systematically collect arguments and opinions of experts about the proposed findings (Van Zolingen & Klaassen, 2003). Additionally, an audit trail, making research choices transparent, was kept.

2.1 Primary teacher educators for science education

Two semi-structured interviews were conducted with primary teacher educators for science education. These were selected non-randomly. Both work at a Dutch university for teacher education. They were interviewed following an interview scheme, which was not pilot tested, to determine concepts related to animals that they considered important to include in primary science education. In particular, they were asked for arguments supporting their choices. It was expected that most relevant arguments would be derived from these two interviews, because the respondents are part of a fairly homogenous group. The interviews were transcribed verbally and analyzed qualitatively together with field notes. To verify the data, a member-check with both teachers was carried out.

2.2 Analysis pupil textbooks for primary science education

To investigate how the concept animal is reflected in pupil textbooks for primary science education, three textbook series for primary science education have been analyzed on concepts related to animals. It is possible that concepts were missed, because no verification was carried out. Also, guidelines justifying content choices were searched for. Pupil textbooks and manuals of the textbooks *Leefwereld* (Van Bussel et al., 1999), *Natuurlijk* (Brijker et al., n.d.) and *NatuNiek* (Janssen et al., 2007) were used. *Leefwereld* and *Natuurlijk* are most often used. Each has a share of ten to twenty per cent in primary schools. *NatuNiek* has a share of 8 per cent (Thijssen, Van der Schoot, & Hemker, 2011). Textbooks for pupils aged 8-9 and 11-12 were used. In addition, for the method *Leefwereld* an activity book for kindergarten children was analyzed. The analysis was done by categorizing concepts in a matrix, that contains 23 biological concepts relevant for primary education, obtained from the conceptual framework (Van Graft et al., 2009). One of the supervisors of the study verified this categorization. It resulted in a reflection of the concept animal in pupil textbooks.

2.3 Questionnaire

To identify important underlying concepts connected to the concept animal and arguments supporting this, viewpoints of different experts were asked by a questionnaire. An expert was defined as someone with expertise in the concept-context approach, curriculum development, and/or primary science education. The non-random selection of experts followed a selection procedure described by Okoli and Pawlowski (2004). Initially 22 people were approached by email. A total of sixteen experts was selected for the questionnaire. Experts were also asked to participate in a focus group discussion. Eight of the selected experts participated in both the questionnaire and focus group discussion, according to Van Zolingen and Klaassen (2003) an appropriate number of participants in a Delphi study. Ultimately, one expert dropped out and only filled in the questionnaire, leaving seven experts for the discussion. The nine experts who only filled in the questionnaire included two PhDs making use of the concept-context approach, a curriculum developer, a member of the commission for the reform of Dutch biology education (CVBO), working at the Institute of Bioscience, a secondary biology teacher and CVBO member, a CVBO member and teacher educator in secondary education, two primary teacher educators for science education, and one education specialist from the Netherlands Institute for Curriculum Development (SLO). Most of them had a background as biologist. The questionnaire contained different items to investigate what experts considered important concepts about animals for primary science education, for example ‘What do you think pupils in primary education should learn about animals and why do you think that?’. The items were reviewed by the supervisors, but no pilot was conducted. The results of the questionnaire were qualitatively analyzed and summarized. Also, the frequency of guidelines was noted. No verification of the results has occurred. A report of the questionnaire outcomes of the seven experts who would participate in the focus group discussion, was sent back to them.

2.4 Primary school pupils

For the interviews and class discussions with pupils one primary school was selected on availability. The school in question is a Protestant school with 220 pupils in Amersfoort, a medium sized city. Three interviews with pupils, each with two pupils of the same age together, were carried out (ages 4/5, 8/9 and 12/13). The pupils, four boys and two girls, were selected by their teacher. Three classes, consisting of 22-27 pupils, aged 4, 8 and 12 years, participated in a class discussion led by the teacher to prevent contingencies in interview outcomes. Both the interviews and class discussions were held on the same day. The pupils were asked to choose one photograph out of six (Figure 2) that was appealing to them during both the interviews and class discussions. Each photograph depicted one of six everyday life contexts in which animals play a role. Whether the photographs were representative for the contexts was not verified. Subsequently, the pupils were asked, following an interview scheme, to explain their choices to identify interests. The interviews and class discussions were transcribed verbatim. A quantitative analysis was performed by selecting a photograph with the highest frequency of pupils’ choices. Two everyday life contexts were selected based on these frequencies to develop the example elaborations. The findings were analyzed qualitatively to provide a contextualization of the quantitative findings. This contextualization consisted of pupils’ arguments. The analyses were supplemented with field notes. Moreover, some concepts related to animals mentioned by pupils were used for the elaborations.

Figure 2. Six photographs, each depicting an everyday life context in which animals play a role. From left to right, top to bottom, the contexts excursion/holiday, examining nature, school, shop, family, and health care are displayed.

2.5 Focus group discussion

The experts who participated in the focus group discussion included three CVBO members, one education specialist at SLO, one employee of the primary education section at SLO, one test specialist for primary and secondary education at CITO, and one author of a textbook for science education content who also works at Science Center NEMO. Five of them graduated in biology, one in palaeontology and one had a background as education specialist. They were invited for a meeting to discuss the outcomes of the questionnaire of which they received a short report. Ground rules were indicated during the meeting. During the discussion the guidelines and elaborations were presented. The discussion aimed at reaching consensus about the significance of the guidelines that were found and discussing the elaborations on limitations and possibilities. The discussion was transcribed verbatim and analyzed qualitatively. The findings of the meeting were sent back to the experts to ensure member checking.

3. Results

3.1 Guidelines

The identified guidelines were classified into four categories. The categories were chosen and specified during the data analysis process. Three categories reflect the perspectives of Tyler (1973) for the selection of educational objectives, though these perspectives were not used explicitly during the analysis. The three distinguished perspectives from Tyler (1973) are: from the student, from society and from the subject discipline.

One category included pedagogical arguments, which take into account what is of importance for children. This is in accordance with the student perspective as described by Tyler (1973). For example, the level and experiences of children was considered as an important argument by experts who filled in the questionnaire and participated in the focus group discussion.

Another category contained social arguments, which are related with the society perspective. Outcomes of the questionnaire showed a social argument. That is, concepts can be selected when they are of social relevance, e.g. the concept health. Subject arguments constituted the third category and this category reflected the subject discipline perspective. This category contained arguments derived from the essence of animals or biology. For instance, an argument one primary teacher educator for science education put forward was that a particular concept can be selected when it belongs to the essence of organisms. The analysis of the primary science education textbook series also showed subject related guidelines, including the relevance of core objectives for primary education in choosing content. The fourth category consisted of didactical arguments. One argument in this category was made frequently by experts who participated in both the questionnaire and the focus group discussion, namely that you select a concept when it can be linked to other concepts. So, the described outcomes showed various guidelines that can be used to determine curriculum content of the concept animal.

3.2 Related concepts

Many underlying concepts and content can be connected to the concept animal. This varied from concepts as form and function, behaviour and reproduction of animals, besides the relation of animals with their environment. See Figure 3 for more concepts related to the concept animal, which were used in the elaborations.

3.3 Everyday life contexts

During the interview both kindergarten children selected the photograph displaying a veterinarian examining a cat. The girl (age 4) preferred it, because cats are appealing. The boy's (age 5) main reason was that he had a cat himself and he loved cats. During the class discussion most of the children, 13 out of 22, selected the photograph of a skeleton in a museum, with more boys preferring it than girls. Striking was that the two children in the interview also selected the museum in the class discussion instead of their previous choice. Some form of coping might be present in the behaviour of these two pupils. Pupils preferred this photograph, because the skeleton is beautiful or big. Also, some children saw it on television or have been in a museum as depicted themselves.

The two children aged 8-9 years selected the photographs of a veterinarian and the museum during the interview. The girl (age 8) favoured the veterinarian, because it was beautiful. The boy (age 9) chose the museum, because he liked it and the skeleton is big so you can observe it well. In the class discussion with pupils aged 8-9 years, the photograph of the veterinarian was frequently chosen, 12 out of 27, mainly by girls. Pupils explained that they had experienced the situation. The photographs chosen by the two pupils aged 12-13 years were the aquarium and the museum. One boy (age 12) preferred the aquarium, because he had fish of his own, he liked them and it looked beautiful. The other boy (age 13) chose the museum, because it looked very exciting to him due to the fact that dinosaurs are extinct. Also, in this group the photograph of the veterinarian was chosen frequently by pupils (12 out of 24). There were more boys than girls choosing it. The opposite was evident with children in the age of 8-9 years. Pupils gave arguments, including liking cats, having a cat and having experience with the situation. Altogether, the kindergarten pupils were drawn to the museum, whereas the pupils of age 8-9 and 11-12 years were drawn to the veterinarian. Therefore the contexts of excursion/holiday and health care were chosen to develop the elaborations, which are shown in Figure 3.

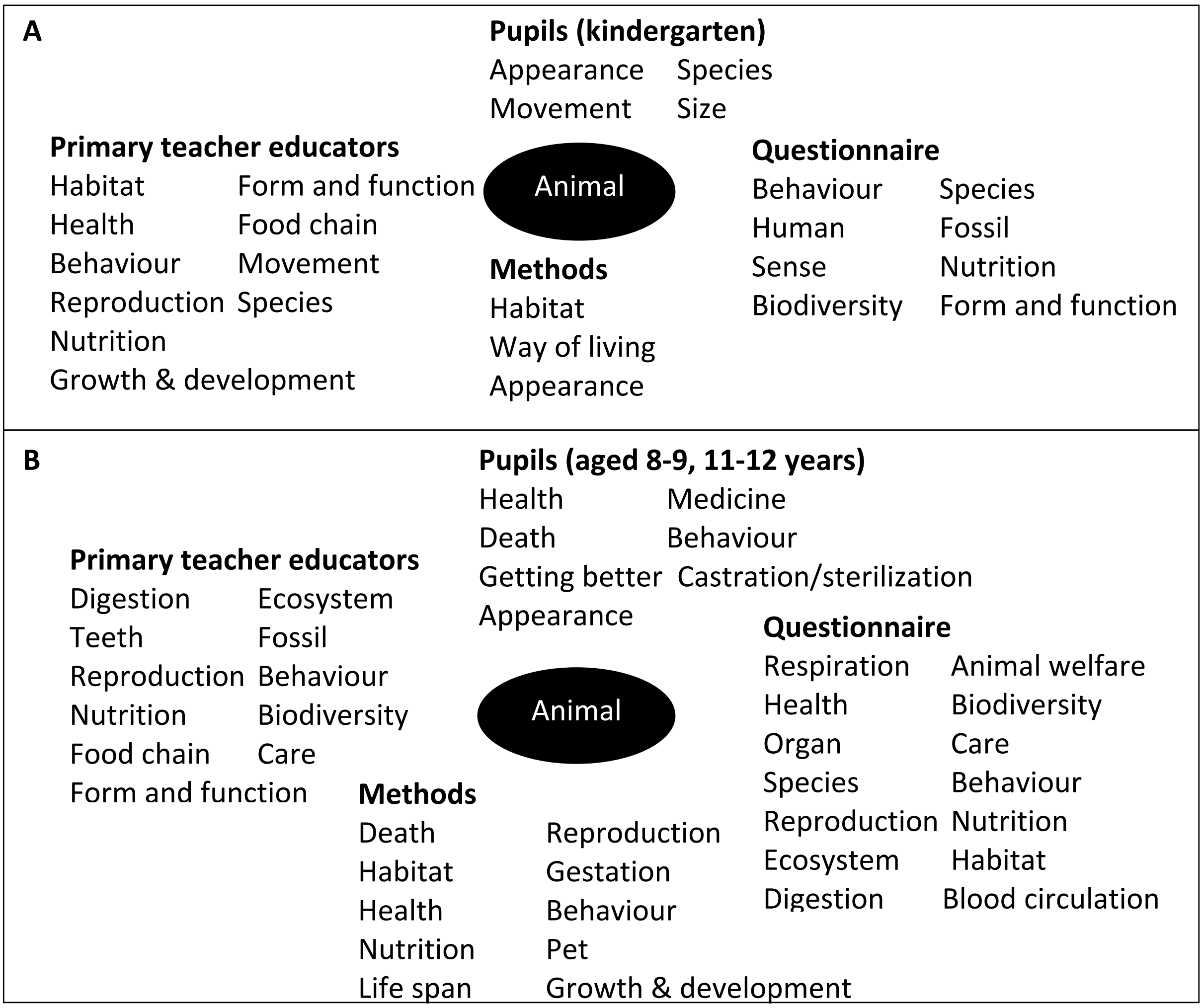

Figure 3. Example elaborations of the concept animal for pupils aged 4-8 years within the context excursion/holiday (A) and for pupils aged 9-12 years within the context health care (B).

3.4 Focus group discussion

In general, as an answer to the question why certain contents in education should be included the known classification of subject, student and society of Tyler (1973) was mentioned by the experts. A balance between these three should be sought. Also, didactical arguments, which made up the presented guidelines were considered important by experts. This category of arguments might be placed between subject and student in the aforementioned classification.

The issue reasoned from the concept-context approach is about visualizing and selecting of concepts in the context pupils participate in and which are functional for them. This functionality has a very high priority in the concept-context approach, and relates to knowledge that substantively is worthwhile. Therefore, it was recommended to look at how concepts are to be defined in a certain context with significance for children. In reaction to the presented guidelines it was stated that the guideline 'choose concepts that can be connected to the level and experiences of children' is perfect. Nevertheless, this guideline cannot be seen as independent from the other guidelines; they are all connected. So when selecting content or concepts it is about knowledge that on the one hand applies to children and on the other side is functional for them in a context. One expert argued that you should first determine a context instead of determining the knowledge in advance. It is important to take into account which context a pupil would participate in and what knowledge can be present in that context. The role of the pupils is very important in this. During the discussion it became clear that a concept cannot be separated from the context; it will vary in relation to the context. A concept will be enriched when a pupil experiences more of it. Various aspects of the concept animal thus can be worked out in different contexts. In addition, it was explicitly stated that a social perspective should be taken into account when selecting concepts. As a result of the discussion the most important argument to select particular concepts was the importance of a concept in the context in which pupils participate or which they orientate themselves on. Finally, the experts agreed that there are three interconnected cornerstones when selecting concepts, that is: the importance of concepts in the context with a social dimension, subject matter and didactics (Figure 4). The interaction between context and subject matter was mentioned explicitly by the experts. The pupil level and educational aims have to be taken into account.

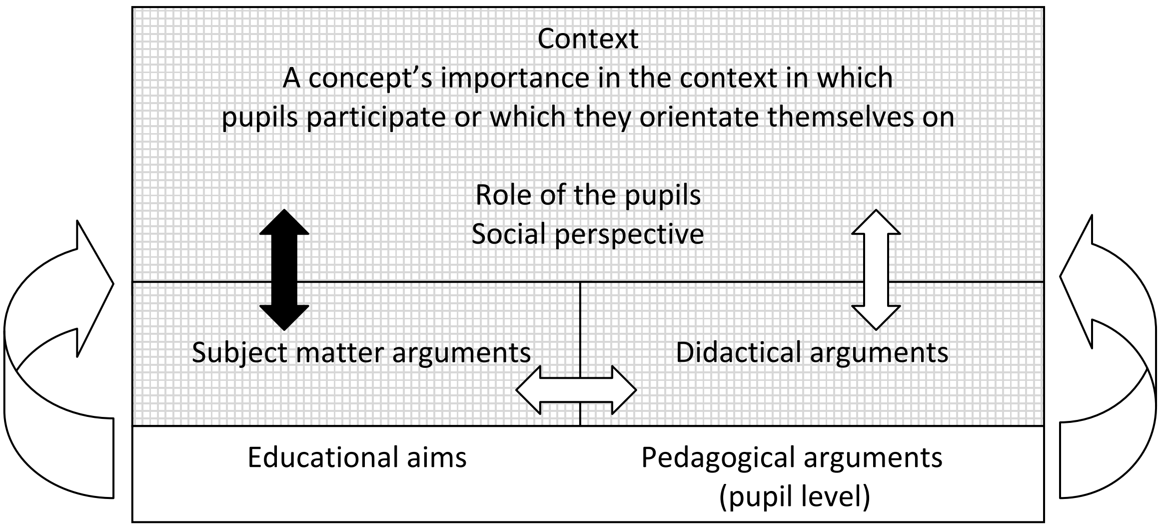

Figure 4. Schematic illustration of three cornerstones in selecting concepts. The white arrows indicate an interaction between cornerstones and the curved arrows indicate an influence on the process of concept selection. The black arrow indicates the explicit interaction between context and subject matter arguments.

The argument of a concept's importance in a context was most qualifying. It was the starting point of reasoning that the experts agreed on. When selecting concepts the discussion should be two-sided, with the sides not isolated from each other. On the one side meaningful contexts should be selected, while on the other biological content in relation to the concept animal present in the selected contexts should be determined. A procedure for selecting concepts was extracted during the discussion (Table 1). The starting point of a concept's importance in a context is clearly reflected in this. In the procedure some of the considerations that were mentioned are included. Above all, it must be said that one should not expect primary teachers to regularly select concepts and contexts in this way.

Table 1. The suggested procedure to select concepts within the concept-context approach

Step	Explanation	Some considerations
1. Select systematically several contexts important for pupils.	Deliberate choices of contexts have to be made to cover the area of contexts pupils should encounter.	- It is a matter of what pupils most often come into contact with (e.g. pets). - Which pupils' activities are possible in the context? - It is about well selected contexts which, when present, retain coherence with a social theme.
2. Determine which (functional) knowledge the pupil encounters in the selected contexts.	Make some elaborations of the selected contexts about present biological content. Which concepts are of importance?	
3. Use an agenda (an extensive description with aspects which should be included in primary science education) of the concept animal to determine whether concepts are sufficient or missing.	Determine from the elaborations (step 2) what concepts and content pupils should encounter. Use the cornerstones (Figure 4) to include or remove concepts.	- Choose a couple of concepts (2 or 3). There are different possibilities. In conceptual development it should be noted that not too much is included.
4. Return to the selected contexts.	Choosing contexts and concepts is an interaction.	

The example elaborations of the concept animal were discussed among experts. It appeared that it depends on many factors, like the activity of the pupils, which concepts can or should be selected in the elaborations. It was made clear that the elaborations cannot themselves lead to the selection of concepts. Therefore an agenda is needed. Holding on strictly to for instance the context of a museum many concepts can be removed. Some of these may yet be suitable for primary education and should therefore be addressed in another context.

4. Conclusions and discussion

This study focused on finding guidelines to make decisions about the concepts that make up the conceptual framework based on the concept-context approach. In particular, the study has described this for the concept animal. As was shown by the findings the three cornerstones (context, subject and didactics) can be used when defining content related to the concept animal, with an emphasis on the cornerstone of context. Regarding the research question, it can be concluded that to arrive at an elaboration of the concept animal the suggested procedure and the three cornerstones should be followed. The procedure should be used as an instruction guide to make decisions about the concept animal. A systematic back and forth movement between contexts and concepts follows from this procedure. With the procedure the example elaborations, and elaborations for other concepts, may be developed further for primary science education.

Since the results indicate that three cornerstones are of relevance, this can be considered as the research's main contribution to further work in this field. Other research has already indicated that different categories of guidelines are present in the field of curriculum choices. The findings are very similar with the three main sources on selecting aims and contents: knowledge, social preparation and personal development (Thijs & Van den Akker, 2009). The knowledge source can be compared with the cornerstone of subject matter, social preparation with the emphasis on a social perspective within selecting a context. The cornerstone of didactics is not evident in the three sources, however it may influence indirectly the personal development. The personal development source can be found in the most essential cornerstone, the context. In it is the position of the pupil. Pupil's experiences, interests and needs are central in this cornerstone, as well as the activities the pupils carry out in the context. The latter is a new aspect that co-determines the concepts that are relevant. Also, Tyler's categorization (1973) is reflected in the three cornerstones. Apparently, this indicates that the findings have a broad support. Still, it is not unimaginable that more or other arguments exist beyond this study. Another possible argument is taking into account the assessment and testing of concepts by pupils. Also, excellent or highly gifted pupils may require other concepts. This affects the selection procedure. Returning to the concept-context approach, the suggested procedure and cornerstones for selecting concepts obviously reflect the importance of the learner. The findings provide a rooted and systematic procedure to moderate the selection of concepts, and for that reason, contribute to a further continuation in working with the concept-context approach in educational practice. Even so, selecting contexts and subsequently concepts is not easy. The findings do not provide strict rules that lead directly to an overview of contexts and concepts for primary education. It can be questioned by whom the contexts and concepts are determined, for instance. Nevertheless, the procedure gives an opportunity to make an effort in selecting concepts, thereby using the three cornerstones as guidance.

Some limitations of the study are evident. Everyday life contexts were selected which were preferred by pupils. However, this does not mean that contexts which are less known or less popular should not be chosen or are not relevant. It may be very useful in introducing pupils to contexts in which they do not participate or which are unknown to them. This is in accordance with a statement made by an expert during the focus group discussion, that pupils should encounter a broad range of contexts. The guidelines and the elaborations were verified by experts, who mainly had a background as biologist or participated in the commission CVBO. It might be interesting to discuss the issue with a broadly composed group of experts. Some of the guidelines that were found seem to appear as general guidelines, which may be useful to other concepts. It raises the question of whether the guidelines as well as the suggested procedure can be generalized for all other concepts. This is an important question for future research. The research study presents an incentive for a further development of the elaborations of concepts, starting with the selection of meaningful contexts and subsequently following the procedure considering the three cornerstones. It gives a potential for curriculum researchers and developers to use the concept-context approach in primary science education.

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12 ARGUMENTS, VALUES & BELIEFS OF PRE-SERVICE TEACHERS DISCUSSING SOCIO-SCIENTIFIC ISSUES

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Abstract

This study explores and compares the argumentations of British and Catalan pre-service teachers given in peer discussions about socio-scientific issues (SSI) related to two topics: Designer Babies and Animals Research. Our main aim is to identify types of arguments, beliefs and values of these two samples.

Data analysis comes from the transcriptions of peer student discussions about the two proposed tasks. The analysis is mainly qualitative although some quantitative comparison has been carried out of argument elements, between these countries and the tasks. We mainly identify from the base of the recognised premises, ideas, beliefs and values, as well political ideology of the pre-service teachers from the two European countries.

Results show us that there are more differences in the types of argument schemes found between the tasks than between the countries. It was found that the arguments for a given country are based on premises which are not used in the other country. In particular, we can deduce from peer discussions beliefs and values of the students. We also identify some particular structures in the argumentation discourses which are indicators of the open or closed thinking of these students.

Keywords: Argumentation, Teacher Training, Science Education, Socio-scientific issues, Pre-service Primary Teachers

1. Introduction and background

The main aim of this study is to explore the argumentations of British and Catalan pre-service teachers given in peer discussions about socio-scientific issues (SSI) related to two topics: Designer Babies and Animals in Research. We are interested as well in knowing whether pre-service teachers from two different European universities think in an open way related to these topics.

Researches into students' scientific preconceptions over the last 30 years demonstrate children develop and maintain ideas and conceptions from an early age. There is agreement that certain differences in the student conceptions may depend on the culture in which they live. Our idea is that thesis and premises of the arguments of students, are related to ideas, conceptions, but also to beliefs and moral or ethical values. Our thought is that patterns of arguments, or schemes, may also be influenced by the culture of the communities and that these argument schemes will present differences in different communities. Both English and Catalan contexts belong to the western cultural context of developed societies; they bear many resemblances but, perhaps, they may have important differences as well, influenced by their specific national, social and cultural context. Our research tries to discover similarities and differences.

Relevant to the aim of our research are the attempts that have been made to identify general reasoning patterns which were not related to the specific topic content of the questionnaire or the interview commonly used in research into students' conceptions in science (Andersson, 1986; Guidoni, 1985, Viennot, 1996). These studies, and others, suggest that beneath the students' specific forms of reasoning some common or general ways of reasoning, or argumentative patterns, can be found and we agree this conception applies also in relation to argumentation about SSI.

In recent years, researchers have become increasingly interested in the discursive interactions that occur during classes and in particular the interest in rhetoric, argumentation and communication in general, and much of the research in Science Education has moved in this direction. Some of the Driver's last works were about argumentation (Driver et al., 2000) and within few years the argumentation became a topic of research (Erduran & Jiménez-Aleixandre, 2007; Buty & Plantin, 2008).

The results of the research on argumentation vary, but there is the agreement that practice in argumentation improves both students' ability to argue and their scientific learning. This amount of research on argumentation is fitting with the central role in doing science or in building moral and ethical values that psychologists and scholars of science education or in ethics (Sadler, 2004; Simoneaux, 2006) attribute to argumentation. For many researchers (Osborne et al., 2001; Albe & Gombert, 2010) SSI offers opportunities for the development of argumentative skills of students, and the interest of students in science learning.

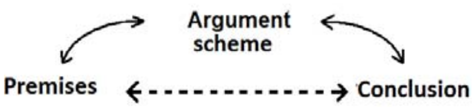
Over the last years, our research group has been mainly interested on the spontaneous forms of reasoning (in the meaning Viennot give to those) related to science topics. More recently we also enlarge our focus on topics that are in the intersection between science and moral and ethics. Our main interest is to contribute in improving science education and face the difficult integration between science and moral and ethical values, and (religious or cultural) beliefs. We consider that the teachers do not know very well the exact way of reasoning of the students. That is the main reason why it is very difficult for the teachers to be able to help in changing the science misconceptions of the students. Besides, in science class, they also have difficulties facing the integration between science and moral-ethical beliefs, and also those of religious or cultural kind. The purpose of this paper is to help the teachers understand the way students argue in order to have elements to improve science education by integrating science with values and beliefs.

2. Theoretical framework

2.1.Perspectives on argumentation

Argumentation has a long tradition as an object of study. In spite of this, there is no universally accepted theory or conception. The study of argumentation is becoming increasingly relevant in several fields of knowledge (philosophy, rhetoric, informal logic, pragmatics, psychology, sociology, ...) and research into argumentation has been approached from several theoretical perspectives (Van Eemeren, 1996).

We agree with the authors who state that argumentation is a *social practice*, with specific characteristics. According to those authors when people argue they elaborate arguments. A single argument is made from several *premises*, a thesis (claim) or *conclusion*, and the *argument scheme*. In a single argument, the scheme is a discursive structure that makes possible to transfer the agreements from the premises to the thesis o conclusion. The argumentative process will be effective if the argument schemes proposed by one individual, or by some arguers, fit with the ones proposed by the others (the audience) (Van Eemeren, & Grootendorst, 2004).



2.2. Analytical framework

As we are interested in argumentations in non-formal contexts (among students) of a plausible character and related to questions in which they have to solve a difference of opinion, our research's analytical framework is based on Perelman (1958, 1982) and Walton (1996, 2006). These theoretical bases come mainly from the field of philosophy and have only been used in few studies in science education research (Duschl, 2008; Castells et al., 2010).

We have discussed the *Theory of Argumentation* (Perelman & Olbrechts-Tyteca, 1958) in an earlier paper (Castells et al., 2007). This theory is summarized in a posterior book (Perelman, 1982). Here we will comment only on the argument schemes of Perelman's book. These schemes are categorized in two broad groups: schemes by 'Association' or 'Connection', which joint separated elements in a new structure, and schemes by 'Dissociation' or 'Separation', which separate elements considered linked or part of a whole, therefore changing systems and notions. Inside these broad categories many other subcategories can be distinguished. In an argumentative discourse, the single arguments combine or link among them, and in this way structuring coherent discourses.

Walton's aim (1996, 2006) is to give a list of forms of inference, from premises to conclusion, named 'argumentation schemes', which represent many common types of argumentation that are familiar in everyday conversations and in the context of a dialogue. In his 1996 book, Walton give a list of 25 argumentative schemes for presumptive argumentation, which were reduced to 17 in his book published in 2006.

3. Research design and method

3.1 Aims

- To find the types of arguments that Catalan and British pre-service teachers use in peer-discussions about SSI focusing on the argument scheme of each identified argument. From this identification a qualitative comparison between both groups is performed.
- To identify ideas, values, beliefs and emotions which are in the base of the students' recognized premises and argument schemes in the arguments about SSI, and to perform a qualitative comparison between both groups of pre-service teachers.
- To identify some argumentative strategies in the process of argumentation in peer-discussion about SSI which give cues about spontaneous argumentative strategies of Catalan and British pre-service teachers.

3.2 Collecting information

Four groups of pre-service primary science teachers from the University of Bristol and of the University of Barcelona were peer-interviewed concerning two tasks about SSI: *Animals in Research* and *Designer Babies* (these tasks are adapted from the English project BEEP). These specific tasks have been chosen because there is a social discussion about these topics in both countries. In fact, there have been presented similar cases in the newspapers of both places. The students participated in the discussions as volunteers and all the groups carried out the tasks outside their normal hours of classes.

3.3 The qualitative analysis and findings

The A**nalysis** involves mainly identifying the single arguments, and in each one, the *theses* (claims) proposed by the students, the *premises* (ideas, beliefs or values below them) from which the theses are transferred and the *argument schemes* used by the students. We also try to identify the *argumentative strategies* that peer-students use in their verbal discussions.

Our analytical framework summarizes the lists of argument schemes of Perelman and Walton, which are completed by some topics from Aristotle. We have proceeded from the theoretical framework to the analysis and from *viceversa* several times arriving to some broad categories, we synthesize in the below list. For the argumentative strategies we don't have previous categories, we proceed from the analysis to the categories that have to be consistent with our argumentation perspective.

Synthesis of types of argument schemes

- **Consequences**; (Means and ends, Casual nexus)
- **Direction** and **Gradualism**
- The **Waste**
- **Verbal classification** or the **Proper**
- **Rule of Justice** and by **Values**
- **Double Hierarchy**, More → More (Aristotle), Preferable (some types)
- From an **Established Rule** (social /natural or scholar)
- **Example**, Illustration and Model
- **Analogy**
- **Quasi-Logical argument** (of Compensation, of Contradiction, of Comparison, of All and Parts, Division, Addition, ...)
- **Popularity**
- **Authority** and Expert opinion
- From **Bias**
- **Preferable** (sure on insure; less damage; look for an alternative; by the difficulty; by the possible; by moral reasons; by the unique,…);
- **Commitment** and **Emotions** (Ethotic arg.)

We illustrate the analysis done with two pieces of the interventions of students from both tasks (see Table 1).

We will illustrate below (pages 184-189), also, the analysis done through a specific dialogue (Br_Animals_1) studied and by looking mainly for *Types of Arguments* and *Argumentative Strategies*. In this particular case, these strategies seem mainly related to a particular argument scheme from Perelman (1982), the 'Double Hierarchy' scheme (DH). Before this illustration, we will summarize what is the scheme of DH (page 183), according to Perelman (Konstaninidou et al, 2010).

Table 1. Analysis of the arguments of the students in two pieces of discussion

ANIMALS IN RESEARCH

Bcn_animals_1
Student Intervention: I am against of this, but I find it logical, because I wouldn't put myself either… it is cruel and I understand that the life of the animals…, I understand that its life is of the same importance but of course, between the animals' life and the mine, well, I would save the mine. It is cruel, but from a sincere point of view, this is what I think and that's all.

Thesis:
I am against of this (*Thesis 1:* To do research with animals), but I find it logical and I accept this at specific level (*Thesis 2*). (Not a general theoretical level)

Premises:
1) I wouldn't put myself either (to be used in experiments ….)
2) Doing experiments with animals is cruel.
3) The life of animals has the same importance than our life. (Implicit: We belong all to the same group of animals)
4) Between save the life of an animal and save the mine, I will choose to save the mine.

Arguments:
Argument 1 (for thesis 1): I'm against research with animals because myself will be not disposal to accept to make experiments with me.
Scheme 1: What is applied to a group (specie) applies to all the members of the group. *Rule of justice (*Perelman*)*
Argument 2 (for thesis 1*):* It is cruel and the life of animals has the same importance that the one of humans
Scheme 2: By consequences (Perelman, Walton) + *Rule of Justice* (Perelman)
Argument 3 (for thesis 2): Between an animal and me I choice to save myself.

Scheme 3: Preferable (a member over the group or specie).

DESIGNER BABIES

Br_Designer Babies_1)
Student Intervention: No (I don't agree to produce babies…). And as you're getting older and they sort of say: Oh, we only had your brother because he was there to cure you', then the younger brother's going to feel like...

Thesis: I don't agree to produce babies.....

Premises:
1) The baby will be useful to cure his brother
2) If a boy knows that it has been produced to cure his brother, this will make to him unhappy.

Arguments:
Argument 1: I don't agree to produce babies because the finality of having a baby is not to cure his brother.
Scheme arg. 1: By consequences (means-ends, causal nexus, Perelman), *From the established rule (against)* (Walton)

Argument 2: I don't agree to produce babies because conceiving a baby in order to help another child can produce unhappiness to this baby when he known about this when he became elder.
Scheme arg. 2: By consequences (Walton; Causal nexus, Perelman)

The Double Hierarchy argument (Perelman, 1982)

According to Perelman, arguers use the DH scheme when they take an established series or hierarchy, one accepted by, or at least familiar to an audience, and form a second series on the model of the first, in the process of trying to transfer implications of order or value from the first to the second. The goal of the DH argument is to make a second ordering, possible and plausible. DH arguments are based on *liaisons* either of succession or of coexistence and can be classified among the arguments based on the structure of reality, which are arguments that are based to the nature of things themselves. With this kind of argument, a hierarchy is argued from other hierarchy by a correlation between the terms of one and of the other. The DH usually expresses a relationship of direct or inverse proportionality or, at least, a link between the parts of each hierarchy. This type of argument has an interesting inclusive character because, in fact, it groups three elements (two hierarchies and one relationship), and could be considered like a strategy. The hierarchies could be quantitative or qualitative, but depends on the issue.

Accepted hierarchy	*Relationship*	Hierarchy under discussion
+	Direct / Inverse proportionality Relation term to term	+
$\uparrow$	$\rightarrow$	$\uparrow$
-	Succession or coexistence linkage	-

Figure 1. Double Hierarchy scheme

It is interesting that Perelman (1982) not only presents the argument of DH, but the ways to refute o modify these types of arguments. According this author, the DH arguments can be refuted by three ways:

- Denying the correctness of one of the hierarchies
- Denying the relation between the two hierarchies
- Opposing a different DH from the first presented hierarchy and by this way the necessity to change it.

There are also other ways to refute an argument of DH, for example, dividing the accepted hierarchy which means some order into some parts or classes that, in fact, means a new view of this hierarchy and, in consequence, determines or made the second hierarchy not acceptable.

Illustration of the analysis done about a dialogue related to the *Animals in Research* task

The task begins with a poll students have to answer:

Try to tick this poll BEFORE you read the information below
Are you?
O In favour of all scientific research with animals
O In favour only of medical research with animals
O Against all research with animals
Did you vote with your heart or your head?

The task then gives five opposite views, in fact, they are arguments a favour or against research with animals, we copy in Table 2 this 'opposing views'.

We enter then into the group *Br_animals_1* peer-discussion. This group is integrated by three students (S1, S2, S3).

In their written answer, students answer the poll as:

- I vote against research with animals (S1)
- I vote in favour only of medical research on animals (S2)
- I vote in favour of medical research with animals (S3)

In the oral discussion we find at the beginning:

S1: Okay. I think this because I've always been brought up with animals and been taught that you should care for animals properly and they're just as important as humans. I just do not agree with animal testing at all. And to say that animals are less important than humans is just wrong, I think totally wrong.

This intervention comes from the consideration, in the student's thinking, of the first given 'opposite views'. Student S1 agrees with the thesis from the "Animals rights" lobby, but she agrees with this view because her life experience. She has lived very near to animals and she has evidenced that the animals are not so different to the humans.

When we compare the peer-discussions of this group Br_Animals_1 with the others that carried out the debate, we find that in the majority of the peer-discussions the given hierarchy of the Biomedical lobby (hierarchy between human and animals) is introduced, and then they debate about the validity of this hierarchy (it imply values) by refuting it in several ways or to cause a decreasing of the force of this hierarchy. Sometimes this is done on the base of premises that differ from the ones included in the "opposite ways". We can consider this procedure as an *Argumentative Strategy* of the dialogue.

The hierarchy between human and animals is the main topic in some dialogues, while in others as a secondary topic. We present here the representation of the argument of DH based on the first opposite way: 'human are more valuable than animals' (Figure 2). If one student accepts this value, the thesis (claim) to be defended will be the acceptation of the research with animals.

Accepted Hierarchy	Relationship	Hierarchy under discussion
Life of human are more morally valuable than life of animals		**Morally appropriated to do research with**
+ Life of human	As **more** valuable is their life **less** appropriated to be used in research →	- human
↑		↑
- Life of animals	Inverse relation	+ animals

Figure 2. DH morally valuable life of human / life of animals

We can read this argument of DH as follows: "As human life is **more** morally valuable than animal life, humans are **less** appropiated to be used in medical research than the animal".

Table 2. The opposing views of the task *Animals in Research*

Opposing views

There are many arguments in favor of using animals in medical and other research experiments however those who oppose animal experimentation have presented a variety of counter arguments. Table 2 summarizes some of the arguments and counter arguments that have been used by each of these groups:

"Biomedical" Lobby	**"Animal Rights" Lobby**
Human life is intrinsically more morally valuable than animal life: we are more important than them.	All sentient animals have equal moral worth: their lives are as valuable as ours.
All mammals have the same organs performing the same functions and controlled by the same mechanisms, via hormones or the nervous system. Animal hormones have been used successfully in humans.	Significant species differences mean that it is impossible to extrapolate with any certainty the results of animal experiments to the human situation.
Whilst non-animal methods such as tissue culture, computer modeling, studies of patients and populations are widely used they do not provide enough information to ensure human safety.	Alternatives such as tissue culture, epidemiological studies and computer models can be used instead of testing on animals.

“Biomedical” Lobby	**“Animal Rights” Lobby**
All experiments must be approved by government inspectors, who are doctors and vets with the knowledge and experience to weight any distress involved in an experiment against the potential benefit for science and for humanity.	Pictures of animals in experiments are taken as clear evidence of cruelty.
Research Ethics Committees of funding bodies are rigorous in their consideration of animal welfare and scientist’ rationale for the research when deciding where to deploy their limited monies.	Much research using live animals is thought to be trivial.

At following, we summarize the content of the peer-discussions related to this task. In all the peer-groups the discussion about the hierarchy between humans and animals is included and the DH argument is used, but not in all the peer-groups appears as the main topic (See Table 3).

Table 3. DH human/animals in the peer-discussion about *Animal in Research* task

Groups	In the dialogue there is in any way a discussion about / related to the DH: *As the human life is intrinsically more morally valuable than animal life* (we are more important than them) and as *we think (*premise*) that as less valuable is a life, more appropriated is this life to do research on*. (the animals are morally more appropriated to do research on than humans are)
Br_Animals_1	Yes, it is the main focus of the discussion, but also other issues, many from the list of opposite views given in the task.
Br_Animals_2	It is present, but not exactly as the main focus.
Br_Animals_3	Yes, but like is in the group Br_Animals_2
Br_Animals_4	It begins with the discussion about the hierarchy Human/Animals and after that it turns away to other issues and at the end of the dialogue it appears another time the initial DH.
Bcn_Animals_1	Yes, it is present in the discussion as an important topic, but also other issues that are not directly related with this DH are included in the discussion.
Bcn_Animals_3	The DH is the main focus, but also other issues that are not so related with this DH are in the discussion.
Bcn_Animals_4	It is a very long dialogue which begins discussing about the initial DH, but after that other issues and new hierarchies appear not in order to refute the initial DH but in order to diminish their importance.
Bcn_Animals_5	It is a very long and very rich dialogue in which the initial DH is there, but also new hierarchies appear, as well as new issues to be discussed.

Also other topics are introduced in the discussions of many groups. We illustrate this through one specific dialogue, from the Br_animals_1 group, in the next chapter.

The outline and argumentation (schemes and strategies) in the Br_animals_1

When we analyse all the peer-discussions related to the *Animals in Research* task, we find that the argument of the above DH is in the discussions, but also the application of some procedures or strategies to refute this DH, or to diminish their force, can be recognized. We illustrate this through the study of a peer-group: Br_animals_1.

1 **-** *Life experience* related living with animals is used *to refute the hierarchy human above animals.* (Refutation of the DH by giving an opposite view. See Figure 3)

2 **-** As human are more valuable than animals, *testing drugs with animals is better than with men to prevent bad effects on human*. Illustration of the *Thalidomide case from '70s'*. (Consequence from the DH given in the task) (Figure 3 gives force to the chosen option, this convincing force increases through a specific real case)

3 **-** But they give a concession: 'better *look for an alternative* to animals' research'. (But they are open to alternatives).

4 **-** Other student accepts *only animals' research for medical purposes, not for other ones, like cosmetics*. (Limitation of the finality of the research with animals, we can see here one arg. 'by division', from Quasilogics (Perelman), they divide the end in two: for medical research and for cosmetics)

5 **-** One student says: 'we can *accept by necessity Animals in Research* to prevent adverse effects on humans' (better with animals than with humans, because it is a necessity) (it corresponds to a scheme of Means and ends, from Perelman)

6 **-** And she considers as an inconvenient that 'the genetics is different, and the *research's results will be not sure on the humans'*. (It is a higher thinking seeing an inconvenient in the defended position. Related to arguments, if we consider as an arg. means-ends, this appreciation of genetics diminishes the end.)

7 **-** They agree that *the only way at present is with animals, if there were alternative, better the alternative*. (They are open to alternatives. We can see here an argument Means-ends, the means we have, justify the end, Perelman)

8 **-** Some students *accept that doctors will act ethically and will try to decrease any distress to animals*. (It shows a faith in the agents of the science, they have ethical values. It can be considered arg. by Authority)

9 **-** Although *we don't know the distress of animals because they don't talk, but today it is the only way to do this research*, if in the future there are *alternative*, we will agree with these. (Thinking in a critical way, animals can't talk about its suffering, and they are open to alternatives. Here a new DH is introduced: decision power / morally suitable to be used in research, we represent it in Figure 3)

10 **-** One student *disagrees with a specific case with a rat*, which consider without medical use. (There is a thinking against doing not necessary experiments)

11 **-** They discuss the bigger worth of human above the animals because *we have not more rights than the animals*. (Discussion about the given DH from the opposing views represented in Figure 2).

12 **-** And also by *genetics we are not so different*. (Argument by Verbal classification, we men and animals belong to the same group, it is used to refute o diminish the initial given DH)

13 **-** Also if *men participate in medical experiments, they do it by choice, but the animals can't choose*. (Being critic with and refuting the initial DH by giving an ethical reason, it can be taken as an arg. from Rule of Justice, Identity (Perelman) and from ethical principles; also we can consider that the refutation of the initial DH is done by giving an alternative DH, see Figure 3).

Figure 3. DH decision power / morally appropriated for research

Accepted Hierarchy	Relationship	Hierarchy under discussion
Own decision power	As **more** decision power has **less** morally appropriated to be used in research	**Morally appropriated to do research with**
+ men (Yes)		- men
- animals (Not)	Inverse relation	+ animals

14 **-** Somebody presents *a case of medical test that caused serious bad effect on people*, if those people were asked about the poll of this task, *they will vote surely against any medical research*. (There is critique about not ethics in medical research, or personal implication, arg. From Commitment, Walton)

15 **-** One *student talks in a very personal way*: We can agree against research on animals because *we don't need to use something that needed research on animals, if we had, and there was no other choice, probably, we changed opinion*. (Personal view, it presents a way to refute the thesis of going against research with animals (a DH opposite to the given initial one, Figure 2) by a personal case, this is a refutation of a DH by refuting the accepted hierarchy considering the group is not uniform, there are differences into the group of the accepted hierarchy)

16 **-** A student presents *the alternative of using criminals in prison instead of animals*. (This goes against the initial DH human/animals) defending that serious criminals, like paedophiles, can be used in the final stage of the research because they have loss all the rights (so, are below animals). Here is a refutation of the given DH of Figure 2, dividing the group of human in classes (good men, criminal men, serious criminal men) and presenting an alternative hierarchy: serious criminal men are below animals, better using criminal men than animals in medical research. After that, someone justifies this new hierarchy saying: the criminal

offenders are loss all the human rights. It can be considered also as arg. of Verbal classification (Walton), they don't belong to the human class, see Figure 4).

17 **-** This student also defends this idea because: '*we pay tax to keep these criminals alive in prison*, where they live fantastic, TV, sport facilities,... more than I never seen in schools'. (Arg. from Waste, Perelman)

Figure 4. DH live beings / morally appropriated for research

Accepted Hierarchy	Relationship	Hierarchy under discussion
Having rights		**Morally appropriated to do research with**
+ normal men (Yes)	As **more** rights has **less** morally appropriated to be used in research	- appropiated
animals		
- serious criminal men (Not)	Inverse relation	+ appropiated

To appreciate differences in values and ideology, we can see the summaries written after the dialogues from two group of students.

> We all agree that testing on animals for cosmetics is unacceptable and not needed. One specific student believed that testing on animals is wrong full stop, but she does understand that things do need to be tested and animals seem to be the only available method. Most of us think that testing things on rapists and serious offenders (Paedophiles) could provide an alternative. Other student feels that these people have lost all rights. (Br_animals_1, Bristol)

> In the discussion several topics have gone out like argue with arguments that were given but after the discussion nobody has changed his opinion. The main arguments have been: 1) We belong to the same group of animals, if I defend a thing (research with animals, I have to defend the other (research with people). 2) We would like a solution for the Medicine but nobody wants to be a body for experimentation. (Bcn_animals_1, Barcelona)

Analysis and findings in relation to the Designer Babies' research task.

The process of the analysis related to the second task, *Designer Babies*, is the same we have done in the first task. However, the argumentative strategies in some groups are a little different; they relate more to ethical and socio-political ideologie, and imply also ethical or socio-political values or beliefs, than to the consideration of a hierarchy accepted for a lot of people which can be discussed or criticizsed. Because of the length of this paper, we will not detail more the analysis and categories of the argumentative strategies found in the dialogues of this second task.

These findings does not contradict the fact that in some dialogues we can find also the '*Double Hierarchy'* argument, as in the example we present in Table 4.

Table 4. Illustration of the analysis of an intervention related to Design Babies task

Bcn_Design Babies_5

Student's intervention: Let's see. First of all, we take into account that we always try not to create people to our taste, but to research a cure for other sick people. .... I think that foetuses neither have conscience, nor they are persons yet, nor they are independent living beings. Consequently, I think that they can be used to cure those that have conscience, those that are independent living beings, and I think on what later is asked about the umbilical cord, that not only the father can give the assent, but I also think that it should be compulsory to do this because it does not imply any damage for the baby, and can benefit others that are sick

Thesis:

Thesis 1: I think that the foetuses can be used to cure sick people.

Thesis 2: The father has to give the assent that the umbilical cord is used to medical applications.

Arguments:

Argument 1: As **more** conscience has an individual, **more** person is (premisa). As the foethuses are individual without conscience, they will be below the hierarchy of any born person. And, as we think as **more** person is an individual, **less** morally appropiated is to do research on (premisa), so, to do research on foetuses is **more** appropriated than to do research on born persons. (DH argument) Imply some values/beliefs about the foethuses, they don't have conscience and so they are not persons.

Argument 2: The father have to give assent about the use of umbilical cord because it does not imply any damage for the baby and can benefit others that are sick. (Arg. From consequences (negative) and Arg. From consequences (positive)

Premises:

P1: We talk about new research to cure other sick people but not to create people to our taste. (General premise that don't intervene in the arguments here)

(In Argument 1) P2:The foetuses don't have conscience, they are not persons yet.

P3: There is a hierarchy of being person [not being person yet (not having conscience)--→ being person (having conscience)].

(In Argument 2) P4: The use of the umbilical cord for medical applications doesn't imply any damage for the baby

P5: The umbilical cord can be used to cure other people that are sick.

3.4 Quantitative analysis and results

We present some results giving frequencies or/and percentages, but only to make the results more "visible" because, really, our study is not a statistical comparison, but a descriptive qualitative comparison.

1) Counting arguments by tasks (Bristol + Barcelona)

The proposed tasks favour students' argumentation. In the discussions of these tasks we find the higher number of arguments in the *Designer Babies* task. Numbers of arguments correspond to the number of identified arguments in the total of dialogues of dialogues, the number is counted from the identified thesis and from the reasons given in each thesis.

Table 5. Counting arguments by tasks (Bristol + Barcelona)

Task	Total Number of Arguments	Duration (mi) (Total by task)	Number of Arguments per minute (mean)
Animals	**156**	70.25	**2.22**
Designer Babies	**193**	72.97	**2.65**
Mean	174.5		2.44
Total	349		

The *Designer Babies* task favourites given more arguments than the *Animal in Research* tasks, and also the rate of arguments / time is a little higher in this task.

2) Counting arguments by tasks and separated countries

Table 6. Counting arguments by tasks (Bristol + Barcelona)

Task	Bristol (Total Num. of Arg.)	Num Arg/ Duration (mean) Br	Barcelona (Total Num. of Arg.)	Num Arg/ Duration (mean) BCN	Total Number of Arguments
Animals	**69**	2.90	**87**	1.87	156
Des. babies	**102**	3.39	**91**	2.12	193
Mean	85.5		89		174.5
Total	**171**		**178**		349

There is only a small difference in the number of arguments given in both tasks between Bristol and Barcelona. Despite of this, students in Bristol, in both tasks, give a bigger number of arguments/minute than students do in Barcelona. Is it a cultural o linguistic difference?

3) Types of argumentative schemes in the total sample and by countries

In the specific context of these SSI tasks, some types of argumentative schemes appear more frequently than others. The most frequent in the *total sample* (Bristol + Barcelona) (349 arguments) are, in descending order:

Consequences/Means and End (105) 30.1%; Verbal classification/ the Proper (61) 17.5%; Double Hierarchy; More → More; Some of Preference (less damage, by the difficulty, by the possible, ...) (37) 10.6%; the Waste (28) 8.0%; from an Established rule (social/natural) (27) 7.7%; Rule of Justice/ Values (26) 7.4%; Example/Illustration/Model/Precedent (18) 5.2%; Direction/Gradualism/Slope soaped (16) 4.6%; Emotions/Commitment (15) 4.3%; Analogy/Model/Methafor (8) 2.3%; From Expert opinion/Authority (6) 1.7; Quasi-Logical (by Comparison, by Division, the Whole and its parts....) (2) 0.5%.

There are some differences between the two samples of Bristol and Barcelona but not very relevant.

4) Counting types of argumentative schemes by tasks and countries

Differences between the frequencies of types of argumentative schemes by tasks are found, some types of schemes are found only or with a very small frequency in one of the tasks. We will not give the quantitative detail of the differences between tasks, but only comment about some of the biggest differences. For example, the argument from the Waste is mainly related to the task *Designer Babies* and is found more in Barcelona than in Bristol. The argument of the Direction or Gradualism has a large percentage in the *Designer Babies* task and in the sample from Bristol. The Double Hierarchy argument and the More-> more argument can be found in both tasks but with bigger percentage in the *Animals in Research* task. The *Rule of* Justice appears in both tasks but with larger percentage in the *Animals in Research* task. Other schemes are found in both tasks in a very similar percentage as the Verbal classification or the Proper argument, as well as the argument by Consequences which is given with the large percentage in both tasks and countries.

Our results agree with other research results that say that the types of arguments depend on the features of the specific task, one of these can be the content of the task indicating a field depending on the reasoning of the students. We have found this result also in the part of our research in which students performed tasks about scientific topics (Castells, Erduran & Konstantinidou, 2010). Using tasks that are different by several specific features, one of which is the way we present the tasks, we found their influence on the types of arguments the students use (Konstantinidou, A., Castells, M. & Cerveró, J.M., 2012). This happened, e.g., when we included arguments in the presentation of the task as we do in the *Animals in Research* task, e.g., we consider that the rich dialogues we collect are caused by the presented arguments in this task.

3.5 Identifying beliefs, values, emotions and ideology through the premises of the arguments

The identified premises are, like the types of argumentative schemes, tasks-dependent. As we might expect because the demands of the tasks, the premises based on school knowledge are not found in these socio scientific tasks, but we find some personal experiences or information from the media. Also premises based on beliefs, moral or ethical values or socio-political ideologies are the base of the arguments of students discussing SSI, as well the premises based on emotions. In fact, values and emotions are very relevant in the arguments of students, but also political ideology. Some students based their arguments on the emotions elicited by the case presented in the task, or a similar case that they had experienced or known facing the debate from a very personal point, saying sentences as: “It is an emotional situation, I could think that could be my son that need a therapy of this type or I could think that I could give an embryo that could be my not born son”. These emotions guide the claims they defend, expressing the complex links established in all argument between premises, claims and argumentative schemes. These types of considerations seems be above other scientific or more objective criteria when they have to take a decision. Other examples show students stating controversial questions not solved neither ethically or scientifically, as “does or doesn’t an embryo be a human life?” Some student think very critically as when he states discussing with others: “we can consider an embryo as a life, but on the other side, could we sacrifice the embryo in order to have the option to cure some illness?”

There are some differences between the countries in terms of the premises on which the arguments are built. The Bristol students based more times than the Barcelona students their arguments on facts and knowledge obtained from media, and these students based their arguments more on ethical values or socio-political ideology or emotional implication. There are also coincidences, e.g., when they introduce the hierarchy humans/animals, but also differences in the way they refute this. In summary, our analysis has been useful to detect some important differences in relation to moral and ethical values and in socio-political ideology. We find that British students are more confident with the Government than the Catalan students, these don’t think the government would guarantee that the research with animal will be done applying ethical principles.

There are not very big differences between countries related the open thinking they show, the majority of students don’t change their opinions during the discussion, but a general impression is that British students are more in the right side of the political ideology, on the contrary many students from Barcelona show a more open thinking and situated in the left side of the political ideology.

4. Discussion and conclusions

Our analytical framework has been built on different theories of argumentation which, among other aspects, focus on non-formal types of argumentative schemes. The use of several theories of argumentation has been useful to produce a wide list for the categorization of students’ arguments answering activities related to SSI that also conform to spontaneous common reasoning.

As a main conclusion, we can say that the way students argue is not so different in the two contexts studied, Bristol and Barcelona, in relation to the types of argument schemes used, in fact, pre-service teachers from both places share the same patterns or schemes of arguments, although not always with equal percentages. These difference in the percentages are explained by the relationship between tasks' features (among other, its content) and types of argument schemes and the argumentative strategies recognised in the dialogues, which is also a conclusion of our research. In a different way, the social cultural context influences on the type of premises of the arguments, which can be values and hierarchy of values, and the beliefs and political ideology that are below these premises.

The analysis done is useful both for a deep understanding of students ideas, values or beliefs and of types of arguments and argumentative strategies. This knowledge provides a "tool" to contribute to face not suitable ideas, beliefs, or values and to help students to improve their attitudes to take decisions in a democratic society. For example, the knowledge of the "double hierarchy" structure can be a "tool" for teachers to refute or to weaken some arguments and so, the ideas or values of students which are below the arguments.

The study shows that the students participating in the discussion engage in authentic dialogues, asking and answering questions. Some of the students' questions asked to justify or refute the theses presented by others are relevant for the advancement of the argumentation, but the arguments are not directed enough to the premises; students do not have convincing arguments for maintain or amending the theses proposed. It seems that the intervention of the teacher is very necessary to guide the discussion along relevant points.

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13 THE APPLICATION OF CONCEPT MAPS IN TEACHING INVERTEBRATE ZOOLOGY

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Abstract

In this paper a comparison is made between the level of efficiency obtained when using concept maps vs. the conventional expository teaching approach in the framework of the zoology curriculum in course of Anatomy and morphology of invertebrates for the undergraduate students at the University of Belgrade – Faculty of Biology. In order to accomplish the tasks of this paper, a model of a pedagogical experiment with parallel groups [experimental (E) and control (C)] was applied, involving 160 students.

The aim was to identify and measure the differences, and compare the efficiencies of these two approaches of teaching.

The E group was presented the course content through teaching instruction which included the elaboration of concept maps. The students from E group, after brief oral presentation by teacher, had to fill-out concept maps, which were related to the five characteristics of the Annelids. The C group was presented the same zoology content through conventional expository instruction-the traditional lecturing model, which is consisted of classical teaching methods: oral presentations, illustrations and demonstrations.

Using this experimental design, we determined that the application of concept maps was more efficient in terms of quantity and quality of knowledge acquired by students in tested teaching field.

1. Introduction

Teaching biology is characterized by a wide range of instructional approaches, methods and teaching tools, in accordance with the program content, the teaching objectives and tasks.

Concept mapping is one of the numerous teaching tools, which can be used in teaching biology (Kinchin, 2000). It is a process of constructing learning maps based on the theories of constructivist (Duffy, Lowyck, & Jonassen, 1992; Richardson, 1997) and meaningful students' learning (Novak & Canas, 2007).

Concept maps are composed of concepts linked by certain correlations in a hierarchical structure. The most important concepts usually are linked by highly informative linking statements which are settled on the labelled lines (Kinchin, 2011). Linking statements need to be valid and to relate concepts in some meaningful way (Buntting, Coll, & Campell, 2006).

Concept mapping is very effective strategy and helps students to learn meaningfully by making explicit the links between scientific concepts (Fisher, Wandersee, & Moody, 2000).

Qualitative approach to concept map analysis can be used for improving teaching process in sense of more effective learning and helping students to integrate their knowledge and build upon their existing naive concepts (Kinchin, Hay, & Adams, 2000). They prevent the existence of gaps in knowledge and misunderstandings (Willson & Williams, 1996), and generally have positive effects on students attitudes and achievements (Horton et al., 1993).

Concept maps can be used as an "expressed model" to investigate students' mental models regarding to the teaching content (Chang, 2007). Mental models are learners' internal conceptual frameworks, and concept maps are external and visual structures. Based upon these similarities, there is evidence for the acceptance of concept maps as an expressed model in order to examine students' mental models (Chang, 2007). It was pointed out that the use of analogies and mental models can enhance student understanding of complex and abstract scientific conceptions (Coll, France, & Taylor, 2005).

Concept maps are very effective for improving knowledge and critical thinking (Kinchin, Streatfield, & Hay, 2010). They are often applied in teaching science and widely described as a tool that can support and enhance students' learning in science classrooms (Kinchin, 2001). Also, they can be used in curriculum planning (Edmondson, 1995; Loertscher, 2011) and for presenting materials to students (Kinchin & Cabot, 2007; Kinchin et al., 2000). They can be tools for measuring and validation (evaluation) of students' knowledge (Herl, Baker, & Niemi, 1996; Kinchin, 2000a; Hay & Kinchin, 2006), or some combination for instruction and evaluation (Peters & Beson, 2010).

Concept mapping has been reported to aid collaborative learning (Sizmur & Osborne, 1997) and to improve students' problem solving (Okebukola, 1992; Buntting et al.., 2006).

Some studies evaluated their application in tertiary biology courses (Smith & Dwyer, 1995; Roberts, 1999; Yarden, Marcbach-Ad, & Gershani, 2004; Buntting et al. 2006; Amundsen, Weston, & Mc Alpine, 2008; Hay, Kinchin, & Lygo-Baker 2008). Results of those studies shown that it is the effective teaching and learning strategy in tertiary tutorial classes.

It has been proven that concept mapping gives the students an opportunity to participate in a far more comprehensive learning process, which is very relevant to the professional practice requirements (Akinsanya & Williams, 2004).

Particularly, it is important, that students in mastering the biology content, continuously and timely gain the information about successfulness of their mastering this content. According to this, various types of feedback information for students have been developed. The effects of feedback were tested with the help of concept mappings.

The efficient application of concept maps in Biomedical Sciences and education is evident (González, Palencia, Umaña, Galindo, & Villafrade, 2008; Moni, Beswick, & Moni, 2005; Sandee, 2005). The effectiveness of concept maps produced by students using paper and pencil was specifically examined (Chang, Sung, & Chen, 2001).

Science courses generally have hierarchical structure of important concepts (Donald, 2002; Kinchin, 2011). This is in correlation with the hierarchical and integrated characteristics of concept maps (Novak, 2010).

Particular consideration of the structure of the zoology courses contents together with the above-mentioned findings concerning the use of concept maps, show the suitability for applying the elaboration of concept maps, like learning tools to externalise knowledge and critical thinking in the Anatomy and morphology of invertebrate course.

2. Research design and method

2.1 Aims and objectives

The main task of this research is to experimentally verify the effectiveness of applying concept maps in accomplishing the zoology curriculum in course of Anatomy and morphology of invertebrates for undergraduate students at the University of Belgrade – Faculty of Biology. Research question is: “Does the application of concept maps contribute to the better acquisition of knowledge?”

The basic-null hypothesis is that there is no statistically significant difference in accomplishing the teaching goals (resulting in students gained knowledge) between the experimental and control groups after introducing the experimental factor (application of concept maps, considered as independent variable) in the experimental group.

The alternative hypothesis is that there is a statistically significant difference in acquired knowledge between the experimental and control groups, after introducing the experimental factor in experimental group. It is expected that the difference in the quality and quantity of the acquired knowledge between the experimental and control groups will favour the experimental group. The aim is to identify and measure this difference, as well as compare the efficiency of these two models of teaching.

2.2 Material and methods

The study included in total 160 undergraduate students from University of Belgrade – Faculty of Biology. To achieve the aims of this research, model of pedagogical experiment with parallel groups [experimental (E) and control (C)] was applied (Appendix 1).

Students were grouped into one E and one C group (Killermann, 1998). Before the introduction of the experimental factor, the groups were made uniform in number of students, gender, and general knowledge of invertebrate zoology as determined by distributing a pre-test of knowledge.

The pre-test was composed of nine tasks in total, which were classified into three broad categories of cognitive domain: knowledge (recall of data or information) (Rank I), comprehension (understanding of meaning) (Rank II) and application (application of that which has been learnt) (Rank III) (Bloom, 1956). Test tasks covered all invertebrate zoology content that had been taught before the topic Annelids (phylum Annelidae).

After equalizing the E and C groups, group E began covering the prepared zoology content (the Annelids) by applying the concept maps. Namely, after brief oral presentation by teacher (PowerPoint presentation: topic Annelids), they get unfilled concept maps (one sample in Appendix 2), which was related to the five characteristics of the annelids (body segmentation, body shell, digestive system, nervous system, genital system). They had to fill-out those concept maps (to write adequate concepts into blank fields), in one instruction period (one week). Each student from E group (after teacher's presentation: topic Annelids), used textbook (to process the text: topic Annelids), pictures and pencil to fill-out those concept maps.

Students in the C group were exposed to the traditional teaching approach (classical model of instruction) for the same teaching contents. Teacher used PowerPoint presentation (topic Annelids) and presented this content through teaching methods: oral presentation, illustrations and demonstrations (during all instructional period). Teacher did not ask the questions about this content. There was no discussion. Only activities for this group of students were listening and watching to what the teacher was saying and showing.

The E and C group were completely separate from each other beyond the classroom setting. They underwent this teaching period simultaneously in different classrooms. In order to prevent any contamination of the design, the students of the E group had no contact with the concept maps outside of the planned period (Kember, 2003).

To determine the knowledge acquired by students using the concept maps and traditional teaching approach, a post-test was applied. It measured the quantity and quality of the students acquired knowledge in the teaching field (the Annelids). The post-test consisted of nine tasks in total (divided into three categories, as was the case in the pre-test) (Appendix 3).

The data and results analyzes were performed using the standard statistical methods/tables-descriptive statistics (sum, percentage frequency, mean, standard deviation, coefficient of variation and Student's t-test for testing differences among the statistics of the same kind). The mean value for individual Ranks is calculated based on the sum of achieved points in the test (the pre- and post-test) divided by the number of students who are doing it. The maximum number of points per Rank was fifth. All these analyses were conducted using the statistical software package Statistica 6 (StatSoft, 2001).

3. Results and discussion

The results of the pre-test are presented in Tables 1, 2.

Table 1. Basic statistical data for the pre-test ($\overline{X}$ - mean of the number of achieved points, S-standard deviation, V - coefficient of variation)

	Rank I			Rank II			Rank III			Total		
Group	$\overline{X}$	S	V	$\overline{X}$	S	V	$\overline{X}$	S	V	$\overline{X}$	S	V
E	3.33	0.77	23.21	1.53	1.15	75.66	2.29	1.52	66.32	7.06	2.81	39.74
C	3.15	0.98	31.24	1.42	1.30	91.59	2.25	1.57	69.95	6.73	3.42	50.87

Table 2. Testing group uniformity in terms of the pre-test, using the t-test (for significance level of $p \leq 0.05$ and a critical value of $t \geq 1.96$*)

Relation	Rank I	Rank II	Rank III	Total
E : C (t value)	1.25	0.51	0.17	0.64

Based on results presented for the pre-test for E and C groups, we can conclude, using Student's t-test for a significant level of $p=0.05$ and a critical value of $t=1.96$, that there is no statistically significant difference in the achieved number of points between the E and C groups in all three levels of tasks and in a test as a whole (Rank I: $t=1.25<1.96$; Rank II: $t=0.51<1.96$; Rank III: $t=0.17<1.96$, a total: $t=0.64<1.96$). These two groups were balanced in terms of general knowledge of zoology before the introduction of the experimental factor.

The results of the post-test are presented in Tables 3, 4.

Table 3. Basic statistical indicators for the post-test ($\overline{X}$ - mean of the number of achieved points, S-standard deviation, V - coefficient of variation)

	Rank I			Rank II			Rank II			Total		
Group	$\overline{X}$	S	V	$\overline{X}$	S	V	$\overline{X}$	S	V	$\overline{X}$	S	V
E	2.85	0.74	26.17	1.28	1.19	93.42	2.21	1.39	62.80	6.34	2.53	39.93
C	2.49	0.77	31.05	0.49	0.78	158.05	1.12	1.29	115.55	4.10	2.37	57.69

Table 4. Testing group uniformity in the post-test, using t-test (for significance level of $p \leq 0.01$ and a critical value of $t \geq 2.58$**)

Relation	Rank I	Rank II	Rank III	Total
E : C (t value)	2.75**	4.61**	4.85**	5.41**

By comparing average values of achieved results, a clear difference can be observed, in terms of levels and in the test as a whole, between E and C groups, favouring the former.

On the basis of the presented result for the post-test of knowledge for E and C groups (Table 3, 4), we can conclude that there are statistically significant differences in the number of points achieved in all three levels of tasks and in the test as a whole, in favour of the E group (Rank I: t=2.75**>2.58; Rank II: t=4.61**>2.58; Rank III: t=4.85**>2.58; a total: t=5.41**>2.58).

The obtained t-coefficient values (marked with an asterisk) are significantly greater than the critical value (by all three ranks and as a whole). Particularly significant are differences in the Rank III test tasks (related to the application of knowledge).

Better results in the post-test of the E group can be explained by differences in the way of teaching the zoology content in the field of Annelids, i.e. by application of the concepts maps in teaching instructions. Students in E group (after brief PowerPoint presentation by the teacher), processed the text (Annelids), from the textbook. It helped them to select and organize relevant information and to filled-out the concept maps. Also, they summarised large amounts of information and integrated their knowledge.

Concept mapping provides an interface between students' cognitive frameworks and textual information. Students need to challenge the science text, they read by "struggling" with it (Slotte & Lonka, 1999). It requires students to process text at a deeper level (Amer, 1994; Kinchin, 2000).

Compared with other results, the research on the effectiveness of programmed instruction with the help of concept maps in the implementation of the biological program content (using the post-test for students) showed that it was very efficient teaching approach (Chang et al., 2001). Also, the results related to the implementation of the ecological program content with the help of concept maps indicate that it is the most efficient method (Ifenthaler, 2010).

The above results concerning the application of concept maps in biological content can be compared with the results of study, which investigated the effects of incorporating concept mapping in teaching chemistry. Those results suggest that it is a plausible method for enhancing student learning (Tan, 2000).

There was investigation about concept-mapping as a tool for enhancing teaching quality in higher education. Results of this study shown that it can be used to transform abstract knowledge and understanding into concrete visual representations that are amenable to compare and measure. Also, the quality of teaching can be significantly enhanced by the use of concept mapping. It enables the engagement of teachers and students in the processes of discovery and makes learning visible. Teachers can use it to promote meaningful learning among their students. (Hay et al., 2008).

Research of concept mapping in supporting university academics' analysis of course content shown that the concept mapping process provide an alternate means to rethink course content. The findings from this study shown that concept maps also highlighted relationships among concept and frequently provided the occasion to make explicit the types of thinking required in the course (Amundsen et al., 2008).

Some studies examined the use of concept maps to measure tertiary science students' understanding of fundamental concept in science education. The results confirm that concept maps contribute to the clarification of students' misconceptions and the meaningful learning (Roberts, L.1999). Also, students seemed to consider concept mapping to be a helpful strategy to determine the relations between concepts and conceptual themes. The first year biology students involved in the concept mapping tutorial sessions were generally positive about their experience. They reporting that concept mapping helped them to link concepts together as well as summarize and recall course content. They found the use of concept mapping enjoyable (Buntting et al., 2006).

4. Conclusions

The research was conducted with the same teaching content (the Annelids), by applying concept maps in the E group and traditional teaching approach in the C group. The E and C groups showed uniform knowledge on the pre-test (in terms of general knowledge of zoology of invertebrates) in task levels I, II and III, as well as in the test as a whole. We can therefore conclude that the groups were uniform in their general knowledge of zoology before the introduction of the experimental factor.

After introduction of the experimental factor-concept maps in the E group, this group performed better on the post-test of knowledge than the C group. The high level of the statistically significant difference is especially noticeable between the groups (in favour of the E group) in the Rank III tasks (application of knowledge in the given teaching field).

The null hypothesis, postulating equality of the acquired knowledge in E and C groups (in the field of Annelids), is rejected on the basis of statistically obtained results. The alternative hypothesis, which states that there is a statistically significant difference between the levels of acquired knowledge in favour of the E group following introduction of the experimental factor (application of concept maps), is confirmed.

It can therefore be concluded that the application of concept maps directly contributed to better learning and knowledge acquisition in the teaching of zoology content (phylum Annelids). In other words, the high quality of the students' acquired knowledge in the tested teaching field was especially significant in the Rank III tasks (application of knowledge).

Modern biology teaching process, especially of zoology curricula, should involve the concept maps, which was explicitly proven to be of high efficiency. Based upon the obtained results of this research, concept maps would be implemented in teaching process (course: Anatomy and morphology of invertebrates). The intention is that in future it becomes the usual and standard teaching methodology in menu anatomy and morphology courses. It will stimulate the students' participation in the teaching process.

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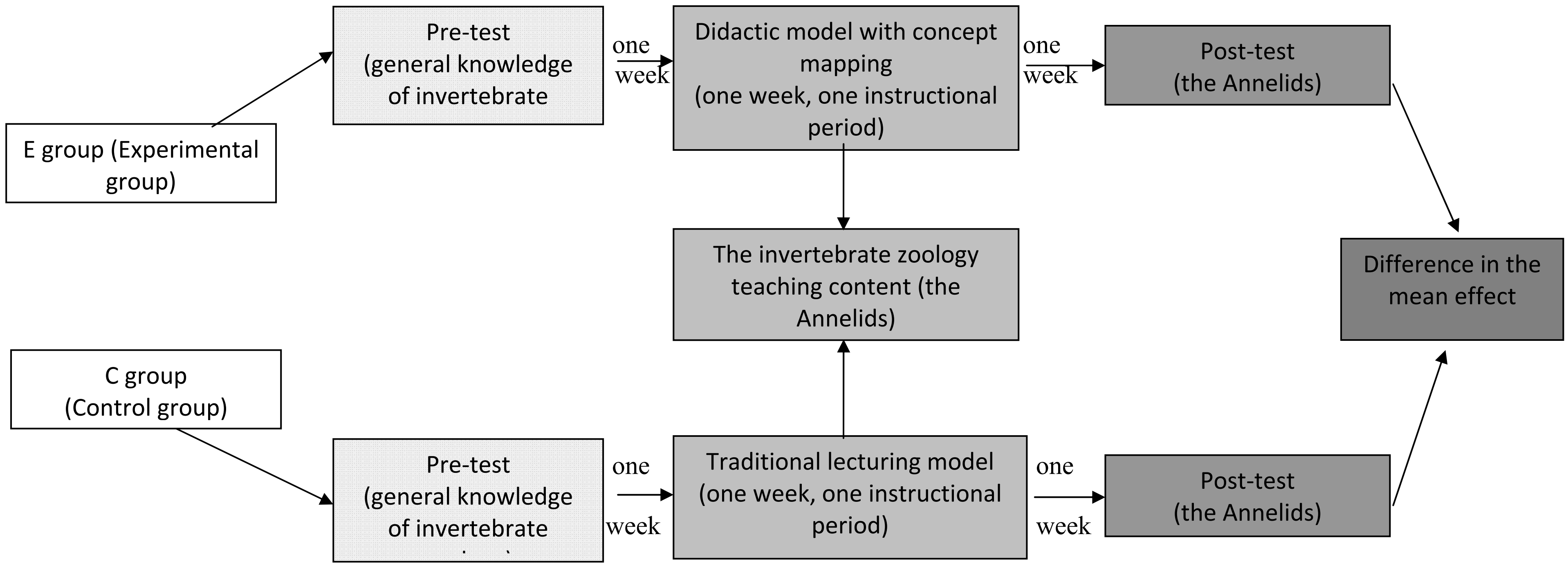
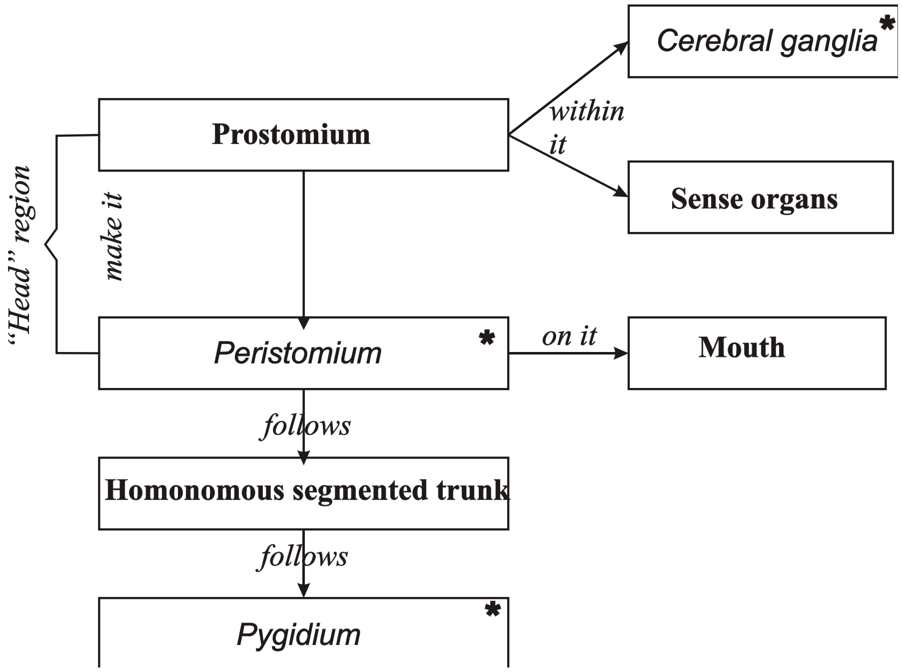
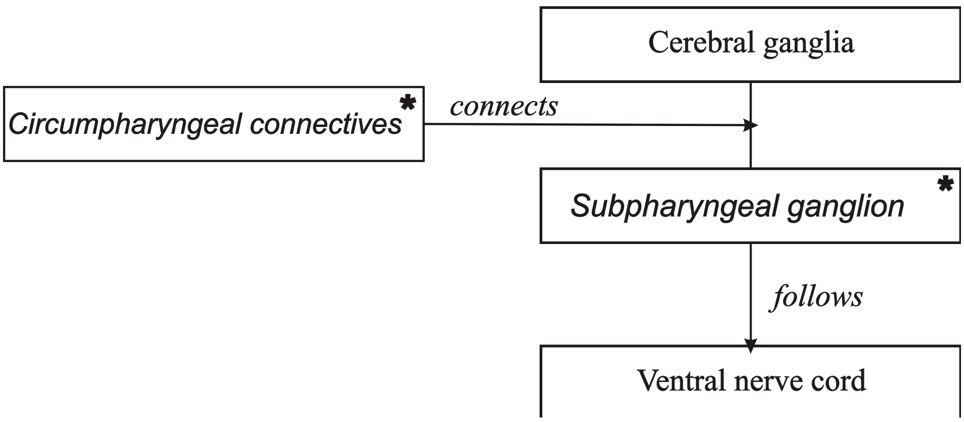
Appendices

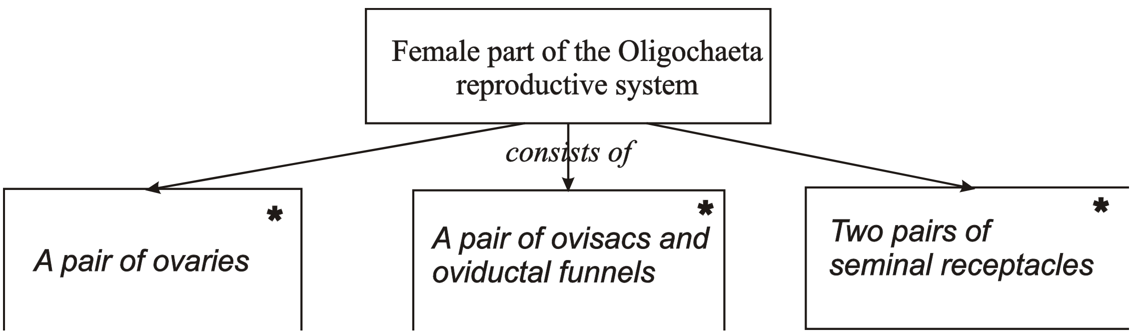
Appendix 1. The model of pedagogical experiment with parallel groups.



Appendix 2. Example of filled-out concept maps on the topic Annelids. The fields assigned with an asterisk were blank at the beginning (the students fill it out during the mastery of the teaching content).







Appendix 3. Example of some tasks used as an indicator of Ranks I, II and III (answers are written in *italic* font style).

Rank I

I Circle the letter of the correct answer:

1. The formation of new segments in the Annelids is done:
a) *in front of pigidium*
b) after pigidium
c) laterally of pigidium
d) on of pigidium

2. Metamerism in Annelids includes:
a) ectoderm and endoderm
b) *ectoderm and mesoderm*
c) ectoderm, mesoderm and endoderm
d) the endoderm

3. Two branched parapodia consist of:
a) two notopodia
b) two neuropodia
c) two ventral branches
d) *notopodium and neuropodium*

4. Nervous system of Annelids consists of:
a) longitudinal nerve cords
b) pairs of ganglia
c) *bilobed cerebral ganglion with ventral nerve cord*
d) nerve net

5. The body surface of Annelids consists of:
a) multilayered epidermis
b) three-layer epidermis
c) two-layer epidermis
d) *single-layer epidermis*

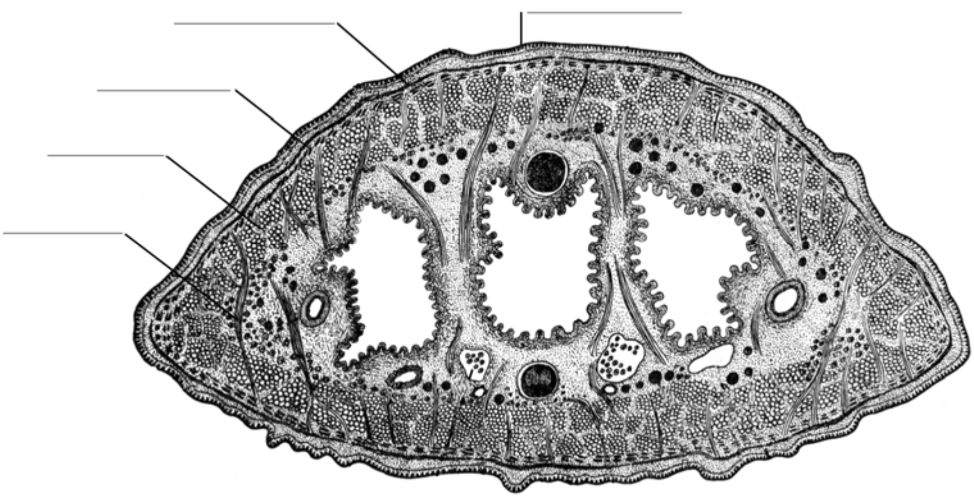
II If the statement is true circle „T“, or „F“ if the statement is false:

6. Ventral pores connecting the coelom of Annelids with the external environment T *F***.**
7. Calciferous glands of earthworm are situated in the intestine T *F*.
8. In the genus *Lumbricus*, the cerebral ganglion („brain“) is situated in the third segment above the pharynx *T* F.
9. Most species of aquatic Oligochaeta have only one pair of testes *T* F.
10. The leeches reproduce asexually T *F*.

Rank II
Fill in the table:
Based on the description, determine and name the concept in the table:

Description of concept	Concept
11. It is created from the peritoneum and synthesize glycogen and fat.	*chloragogen tissue*
12. Dorsal longitudinal folds of intestine of the land Oligochaeta with function to increase absorption.	*typhlosole*
13. Glandular epithelium of mature Oligochaeta which secrete mucus that holds the worms together during the copulation.	*clitellum*
14. The third band of perianal cilia of the Annelid trochophore larvae.	*telotroch*
15. Combinations of coelomoduct and nephridium are termed.	*nephromixia*
16. A short canal derived from coelomic tissue, connecting the coelom with the external environment; often combined with nephridium.	*coelomoduct*
17. The body cavity with peritoneal lining; formed in embryonic mesoderm.	*coelom*
18. Thin, non-cellular protective layer produced by and overlying the epidermis, consists mainly of scleroprotein (not chitin).	*cuticle*
19. One of the two fleshy lateral projections from a body segment, usually bearing chaetae.	*parapodia*
20. A stout supportive chaeta found internally in projecting parapodial rami.	*acicula*

Rank III
On the diagram determine and name only those concepts (structural elements) that form body wall of Leeches (Hirudinea), using serial numbers (in front of concept) to be in a series from the outside to the inside of the body.



(*1. epidermis; 2. circular muscles; 3. oblique muscles; 4. longitudinal muscles; 5. dorso-ventral muscle*).

14 HIGH-SCHOOL TEACHERS' APPROPRIATION OF AN INNOVATIVE CURRICULUM IN BIOINFORMATICS

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Abstract

One of the goals of curriculum developers is to provide learners with opportunities to engage in activities that resemble authentic scientific research. A learning environment (LE) aimed at introducing bioinformatics into a high-school biotechnology majors curriculum through engaging learners in authentic research practices served as the context for this study. A teachers' program aimed at establishing a community of biotechnology teachers who collaborate in implementing the LE was established. One of the goals of the teachers' program was to design an assessment tool for the LE. In this study, we examined how the teachers designed the assessment tool, as a means of probing their knowledge and beliefs in adopting contemporary scientific research into their classroom. The analysis of the assessment tool revealed questions that require the use of conditional knowledge, which is at the heart of performing authentic scientific research. Most of these questions called for coordination between various scientific reasoning practices. The teachers perceived research as combining laboratory experiments and bioinformatics approaches. Thus, the assessment tool represents characteristics of authentic modern scientific research and the teachers' appropriation of the new bioinformatics curriculum, by extending its roots to the 'traditional' curriculum. We envision that an analysis of the rationale and design of the assessment tool developed by the teachers, may not only be applicaple for the characterization of other scientifically authentic assessment tools, but also can serve as a means of exploring teachers' knowledge and beliefs.

Keywords: Authentic science education; Bioinformatics curriculum; Teachers' development program; Assessment; Domain-specific knowledge

1. Introduction

1.1 Authenticity in science education

One of the fundamental goals of curriculum developers is to provide learners with opportunities to engage in scientifically authentic practices. Here we refer to the canonical perspective of authentic science education (following Buxton, 2006), namely practices that resemble authentic scientific research as they are carried-out by the scientific community. This perspective on authenticity is aligned with both the Western scientific canon and the canon for science education standards in the US (National Research Council [NRC], 1996, 2012), Europe (European Union, 2006) and elsewhere (Yarden & Carvalho, 2011). Such practices represent important discipline-specific aspects of science, and may therefore enhance cultivation of students' scientific habits of mind and can contribute to the contextualized understanding of how scientific knowledge is acquired, evaluated, and developed (Samarapungavan et al., 2006). These practices can offer students opportunities to develop a deep understanding of scientific knowledge (Abrams, 1998; Lee & Songer, 2003) and to invoke the reasoning that scientists employ and the epistemology underlying authentic inquiry (Chinn & Malhotra, 2002); they may also lead to a proper conception of the nature of scientific inquiry. Engagement in authentic scientific research practices can foster student participation in practices of inquiry (Chinn & Malhotra, 2002; Falk et al., 2008), and requires continuous coordination between various intervening events of the scientific practice (Chinn & Malhotra, 2002; Falk & Yarden, 2009).

The overall greater complexity of authentic scientific research requires continuous application of conditional knowledge and coordination of declarative and strategic knowledge, while reasoning scientifically and making decisions (Gelbart & Yarden, 2011). Declarative knowledge has been defined as knowing "what" the factual information is, procedural knowledge as knowing "how" to use this knowledge in certain processes or routines, and conditional knowledge as understanding "when and where" to access certain facts or employ particular procedures (Alexander & Judy, 1988). Usage of conditional knowledge, and coordination of facts, procedures and strategies, are not typical of regular school tasks and rarely appear in school learning materials (Chinn & Malhotra, 2002; Yarden, 2009).

1.2 The emergence of bioinformatics

Massive growth in information, due to experimental and technological advances, has led to an absolute requirement for computerized databases to store, organize, and index the data and for specialized tools to view and analyze the data. Bioinformatics is an emerging interdisciplinary field, drawn from fields as diverse as mathematics, physics, computer sciences, engineering, biology, and behavioral science. It applies principles of information sciences and information technologies to make the vast, diverse, and complex life sciences data more understandable and useful, and help to realize its full potential (National Institutes of Health [NIH], 2000). Bioinformatics has revolutionized and redefined how research is carried out, and has had an enormous impact on biotechnology, medicine, industry and related areas (Attwood et al., 2011).

While bioinformatics is increasingly important in modern life sciences, it plays almost no role in high-school science classes. To mirror today's research trends and keep science curricula current, considerable resources are now being devoted to integrating this exciting field and its related databases, tools and technologies into science classrooms (Gallagher et al., 2011; Gelbart & Yarden, 2006; Lewitter & Bourne, 2011; Wefer & Sheppard, 2008) mainly through inquiry-based activities. Incorporation of bioinformatics in education, mainly at the high-school level, presents great opportunities and major challenges for students and teachers, as well as at the curriculum and logistics levels (Cummings & Temple, 2010).

We recently developed a web-based learning environment (LE) (Machluf et al., 2011) that is aimed at introducing bioinformatics into a high-school biotechnology majors curriculum in Israel. The biotechnology curriculum includes obligatory subjects such as genetic engineering and biochemistry, and the elective topics of immunodiagnostics and immunotherapy, tissue culturing, environmental biotechnology, bio-nanotechnology and advanced laboratories, as well as bioinformatics (Israeli Ministry of Education, 2005). In the LE, both pedagogy and technology were recruited for educational purposes aimed at engaging students with scientifically authentic inquiry activities that bring the fruits of bioinformatics to bear on human health quality and expectancy (see http://stwww.weizmann.ac.il/menu/personal/anat_yarden/abstracts/Bioinformatics.pdf). Learners are invited to take part in five authentic inquiry activities in biotechnology using eight different bioinformatics tools and databases. The activities were developed based on primary research articles selected according to (i) the relevance of the scientific context to students' interests; (ii) a clear biotechnological application; (iii) use of a variety of bioinformatics tools and databases that are suitable for the high-school students' cognitive level; (iv) high-impact subjects that are broadly covered in the popular scientific literature and in the public media, and (v) clear connections to principles and techniques in the biotechnology syllabus. In each multistep activity, the students are introduced to the rationale and main goals of the research at hand, and learn how to utilize the bioinformatics tools and databases, similar to the original research plan. The selected bioinformatics tools are basic yet fundamental; they are commonly used by scientists and enable acquisition of central bioinformatics principles and approaches. To proceed in the investigation, the students experience different scientific practices, they are required to coordinate their acquired procedural knowledge, declarative subject-matter knowledge, context-dependent conditional knowledge and prior content knowledge, and also to reason scientifically and make decisions following the strategic plan.

1.3 Teachers' professional development program

Integrating scientific practices, crosscutting concepts and core ideas (following National Research Council [NRC], 2012) into real-world inquiry-based activities for bioinformatics learning and instruction is necessary but not sufficient. We believe that successful implementation of bioinformatics as an elective topic in the biotechnology syllabus is greatly dependent on the teachers, who should become agents of change (Fullan, 1993). Therefore, a teachers' professional development program was established during the 2010-11 academic year. To develop teachers' identities as reform-minded science teachers, the program provides opportunities for participation in scaffolded series of experiences that will build their personal vision and mastery of knowledge and skills, as well as recognition by self and others as reform-enhancing teachers (Luehmann, 2007). The design of the teachers' program stems from a theoretical perspective that views teachers' training, similar to students' learning, as a combination of the constructivist learning perspective (Greeno, 1998) - which encourages active learning that allows opportunities to build one's own knowledge, and the situated learning perspective - which views learning as a process of enculturation into a community of experts by using authentic activities (Brown et al., 1989). The rationale of the program is based on the following guidelines: (i) designing and developing a curriculum, or assessing it, can serve as a vehicle for teachers' professional development and as a driving force for transforming science teaching (Parke & Coble, 1997); (ii) experienced teachers have valuable and unique kinds of knowledge and skills (Shulman, 1987); (iii) the assessment tool is a curriculum requirement that can be recognized by professionals (e.g., the teachers themselves, other teachers, supervisors, educators and developers in bioinformatics) as a meaningful product of the teachers participating in the program.

This study examined how high-school biotechnology teachers design and develop an assessment tool for an innovative LE in bioinformatics, as a means to probe their knowledge and beliefs in adopting contemporary scientific research into their classrooms. Specifically, we asked:

1. What are the characteristics of the assessment tool developed by the teachers?
2. What was the teachers’ rationale behind the development of the assessment tool?

2. Research design and method

2.1 Research context

A teachers' professional development program aimed at establishing a community of teachers who collaborate in adapting the new LE and promoting its implementation was launched at the Weizmann Institute of Science. Four highly qualified in-service biotechnology teachers, from four different high schools across the country, with only limited knowledge in bioinformatics but with experience in implementing innovative learning materials and preparing students for the matriculation exams in biotechnology, were selected to participate in the program (Table 1). The main rationale of this program was to develop teachers' identities as reform-minded teachers, pioneers at the forefront of high-school bioinformatics education, who recruit their knowledge and experience to mutually design and develop bioinformatics instructional means and assessment tools.

Table 1. Participants characteristics

Teacher	Gender	Degree	Years of teaching experience (biotechnology)	Experience in writing matriculation exams	Other duties
1	Male	Ph.D.	30 (13)	Yes	
2	Female	Ph.D.	31 (14)	Yes	National advisor
3	Female	M.Sc.	24 (10)	No	Regional advisor
4	Male	M.Sc.	6 (6)	No	

The program curriculum ran for eight hours weekly over the course of one academic year (37 meetings). Each semester, the teachers participated in a biology course and in seminars in science education research, while most of their time was devoted to collaborative workshops in bioinformatics. These workshops introduced the teachers to the bioinformatics world of research and education while they designed and developed instructional means and assessment tools. The program meetings were instructed and guided by the first two authors of this study, together with science teaching experts and in collaboration with researchers from the field of bioinformatics. During the first part of the program, emphasis was placed on acquisition of theoretical content knowledge, experiencing firsthand practical skills in using bioinformatics tools and databases, and judicious integration of bioinformatics tools alongside experimental techniques in biological reseach. As expected, it was in this phase that teachers exhibited resistance and antagonism to the new materials in bioinformatics, as they claimed to "be afraid of the unfamiliar [bioinformatics] tools" and to "feel like students". In this phase teachers were engaged primarily in understanding the procedures and technical aspects of utilizing the bioinformatics tools, rather than in the broader scientific reseach view. They then became fully familiarized with the LE and its activities, prepared teaching materials, instructed their own students while enacting LE activities, and collaboratively analyzed and reflected on their experiences. In this phase, teachers' attitudes changed into more positive responses toward the LE, and they became less skeptical and more convinced that the bioinformatics LE demands are in line with high-school students' abilities. Then, teachers collaboratively designed and developed an assessment tool that could serve as a model for the national bioinformatics matriculation examination.

2.2 Research design

The assessment tool was designed, developed and refined collaboratively by the teachers over three sessions. Following each session, brain storming was performed with the instructors and the assessment tool was then revised solely by the teachers. The three versions of the assessment tool, and more specifically the questions embedded in them, were analyzed according to three criteria (see below) in order to characterize the assessment tool developed by the teachers, and to uncover tacit knowledge and their perception of bioinformatics research. Furthermore, teachers were interviewed at the end of the year to reveal their rationale behind the development of the assessment tool.

2.3 Data analysis

We examined how the teachers designed and developed an assessment tool for the LE. To study the characteristics of the assessment tool, the questions it included were classified based on three different criteria:

1) Domain-specific knowledge: questions were categorized according to the type of knowledge required to answer them, namely *declarative*, *procedural*, or *conditional* knowledge following (Alexander & Judy, 1988). This knowledge classification framework is of particular relevance to the bioinformatics field and the curricular themes of understanding the theoretical principles underlying each bioinformatics tool, its proper operational use, and the considerations of research-derived selection of bioinformatics tool, its integration and its contribution to experimental research, respectively. For example, in bioinformatics education, understanding the principle of sequence alignment is declarative knowledge, while using a bioinformatics tool to perform sequence alignment is procedural knowledge, and realizing when to align which sequences to what goal is conditional knowledge.
2) Scientific reasoning (following Chinn & Malhotra, 2002): *research questions*: questions that require coordinating different research questions; *methods*: selecting methods and examining their suitability to the research questions; *results*: analyzing the results, and *theoretical explanations*: generating explanations and conclusions. Authentic scientific inquiry involves various processes; the main ones were selected and gathered into these categories.
3) Scientific approach: questions that stem from a biological approach, bioinformatics approach, or a combination of both. Modern bioinformatics-integrated research includes steps that combine both approaches, as well as steps that stem from each approach.

All of the questions were classified independently by two researchers and discussed until 100% agreement was achieved. The frequencies of questions classified into each category were calculated, and a Chi-square test was used for comparisons among groups.

At the end of the year, teachers were interviewed; the interviews were recorded, transcribed, and analyzed bottom-up using classification into episodes and subsequently into categories (following Shkedi, 2005). The teachers were asked to review the significant phases in the training program, the professional goals, educational achievements, implications and their recommendations for the future.

3. Results

3.1 Description of the process

Three main phases were observed in the process of teachers' collaborative design and development of the assessment tool:

1) Topic selection: Initially teachers turned to the scientific literature, seeking papers describing investigations in which advanced experiments and bioinformatics approaches had been combined and recruited to solve current biotechnological questions. This phase was clearly a bottleneck in the process, a "frustrating" phase in the teachers' own words, as they lacked the experience to realize how bioinformatics is integrated into scientific research, the mode of its implicit description in scientific papers, and its contribution. Given a choice of various candidate authentic papers proposed by the program's instructors, teachers selected the article by Gupta et al. (2010).
2) Processing: Teachers met one of the investigators conducting the research to gain insights into the research process, including its experimental and bioinformatics steps. Design principles of the assessment tool were determined, the scientific outline was set, and the relevant bioinformatics information (data records, nucleotide sequences, proteins structures, etc.) was gathered under the instructors' supervision. The outline was composed of a short introduction and three experimentally based sections in which the resultant data were represented using a graph and tables, combined with three sections in which bioinformatics tools were used.
3) Design, development and revision: The teachers focused on designing, developing and refining the assessment tool over three sessions. Following each session, brain storming was conducted with the instructors to analyze the assessment tool as a whole. Theoretical frameworks for analyzing the questions embedded in the assessment tool were discussed, and the assessment tool was then examined and revised solely by the teachers.

3.2 Characteristics of the assessment tool

The questions embedded in the assessment tool were analyzed according to the three criteria used to characterize the assessment tool. During the development and revision of the assessment tool, questions were mainly added (7 in the second version and 1 in the third version) and modified (12 and 9, respectively). Most added questions (5) required the use of conditional knowledge. Only 3 questions were modified such that their characteristics changed. The three versions of the assessment tool were similar, therefore only the analysis of the last version is presented.

The frequency of each of the question types in the assessment tool was calculated using the three criteria (Table 2). The frequency of questions that require the use of declarative knowledge was half that of the questions requiring either procedural or conditional knowledge. Similarly, the frequencies of questions dealing with either a biological approach or a bioinformatics approach were almost equal within each session, whereas the frequency of questions dealing with a combined approach was about twofold lower. Analysis of the frequencies of questions dealing with scientific reasoning revealed that most deal with *results* (57%), while much fewer deal with the *research questions* (14%).

Table 2. Frequencies of questions embedded in the assessment tool classified according to three criteria: Domain-specific knowledge, Scientific approach and Scientific reasoning

Scientific criteria	**Categories**	**Total number of questions (percentage)**[b] (n=28)
Domain-specific knowledge	Declarative	5 (18%)
	Procedural	11 (39%)
	Conditional	12 (43%)
Scientific approach	Biology	12 (43%)
	Bioinformatics	11 (39%)
	Biology and Bioinformatics	5 (18%)
Scientific reasoning[a]	Research questions	4 (14%)
	Methods	7 (25%)
	Results	16 (57%)
	Theoretical explanations	8 (29%)

[a] The sum of questions classified as scientific reasoning is above the overall number of questions due to multiple attributions of several questions.
[b] The number of questions within each category and their percentage of the total number of questions is presented.

A comparison of the frequency of the three types of domain knowledge within questions calling for specific scientific reasoning revealed significant differences in their distribution (Table 3). Questions dealing with *results* called mainly for procedural knowledge and to a lesser extent for conditional knowledge. Questions dealing with either *research questions* or *methods* called almost exclusively for conditional knowledge. In questions calling for *theoretical explanations*, a non-significant over-representation of questions requiring the use of conditional knowledge was observed. Four questions (14%) that required the use of declarative knowledge were not assigned to any of the scientific reasoning categories. Rather, they were based on prior knowledge or on textual information provided in the assessment tool. Conversely, 10 questions (36%), most of them requiring the use of conditional knowledge, were assigned to multiple scientific reasoning categories.

Table 3. Distribution of questions calling for a particular scientific reasoning according to the domain-specific knowledge criterion

Scientific reasoning	**Domain-specific knowledge** **Declarative** (n = 5)	**Procedural** (n = 11)	**Conditional** (n = 12)
Research questions	0	0	4*
Methods	0	1	6*
Results	1	10	5**
Theoretical explanations	1	2	5
Not assigned to any scientific reasoning category	4	0	0
Assignment to a single scientific reasoning category	0	9	5
Assignment to multiple scientific reasoning categories	1	2	7

*$0.01 < P < 0.05$; ** $0.001 < P < 0.01$

3.3 Teachers' rationale

During the interviews broad agreement was expressed by the teachers. The teachers found the development of the assessment tool as the most meaningful activity in the program, and elaborated on the rationale and the design principles underlying its development.

They perceived their 'mission' through their annual and diverse activities as "to speak on behalf of our students and to adapt the learning materials and assessment tool to their level" while making it "relevant to students…challenging yet not frightening" (Teacher #2). They were all satisfied with the assessment tool, and described the process they had gone through as interesting, creative and educational. The assessment tool's format was developed by the teachers with the aim of demonstrating "a clear [biotechnological] research approach, following the sequence of the [original] research, and making clear the rationale behind this sequence… the goal [of the research] should be very clear to the students and it should take them directly to the [bioinformatics] tools" (Teacher #1). The teachers particularly emphasized their attempts to integrate questions calling for application of prior knowledge in biotechnology, mainly key concepts in the biotechnology curriculum, and general inquiry skills while using the bioinformatics tools: "It's great that we could integrate scientific concepts, connect between something in biochemistry like an enzyme activity, and what we see using the Jmol [bioinformatics tool]" (Teacher #1). They also mentioned their attempts to include general scientific skills: "We peppered the questions with more skills such as reading graphs…that are learned in the [school] lab" (Teacher #1). In the same line, the teachers referred to the importance of selecting bioinformatics tools that match the biotechnology curriculum: "It is also important that the bioinformatics tools suit the curriculum…Sequence alignment, for instance, is a central theme in the curriculum, while finding motifs in the gene is not, so I prefer to use the alignment tools" (Teacher #2).

A similar representation of questions calling for either biological or bioinformatics approaches, as well as inclusion of questions that coordinate both approaches, reflect teachers' acquired perception of a research approach as combining laboratory experiments and bioinformatics. This coordination between the research approaches in the assessment tool can be considered another aspect of the authentic scientific research, namely the way scientific knowledge is created and evaluated in the current era of biological sciences. Furthermore, this coordination may reflect teachers' desire to adapt the new curriculum by linking it to the existing 'traditional' one. These interpretations are supported by the analysis of the teachers' interviews. The inclusion of questions that coordinate biological subject matter and the bioinformatics approach was explained as "the whole issue here is to connect the biological approach and what you get by using the bioinformatics tools and biological knowledge!…the integration just jumped out at me! We must find out where the bioinformatics contributes" (Teacher #2). Another teacher explained that "actually we should place a hyphen connecting bioinformatics to biology" and added that "integration should be performed between the biological part, which is seemingly more external and extrovert, and the understanding of [bioinformatics and research] processes. If we'll limit the scenario to 'an enzyme was found' – why would the students think it is interesting?...the synapse [of biology and bioinformatics] should be discussed" (Teacher #1). Another teacher explained that "the hypothesis of the experimental approach is clear to me, but here we integrate a bioinformatics approach, so we have to be very accurate, to show the contribution of the integration" (Teacher #3), and added "the use of the bioinformatics tools did not scare us, but there is a need to connect what you find using the [bioinformatics] tools with the biological knowledge that is deeply established in us…this is the way I'd like to teach it in class" as the other teachers nodded in agreement.

While reflecting on the process of developing the assessment tool, the teachers concurred that it was a long and enjoyable journey, during which they realized how difficult the process of developing authentic research-based materials is, while at the same time learning how to develop such a tool, what and how to assess, and by what means to analyze and classify the questions. Importantly, in the development of the assessment tool, each teacher could "express one's creativity, motivation, desire to contribute, and innovative ideas" (Teacher #2).

4. Discussion

A teachers' professional development program aimed at establishing a community of biotechnology teachers who collaborate in implementing the bioinformatics LE served as the context of this study. Teachers' knowledge and beliefs toward adopting contemporary bioinformatics-integrated research into their classrooms were assessed by both analysis and characterization of an assessment tool for the LE, which was constructed by the teachers, and by interviews to uncover the rationale behind the assessment tool's design and development. The analysis of the questions embedded in the assessment tool revealed that the teachers had integrated a considerable number of questions that require the use of conditional knowledge, a type of knowledge which is at the heart of performing authentic scientific research. Most of these questions require the coordination of multiple scientific reasoning practices. Similar representation of questions stemming from either biological or bioinformatics approaches, as well as inclusion of questions coordinating both approaches, reflected teachers' acquired perception of a research approach as combining laboratory experiments and bioinformatics. These features indicate that the assessment tool represents characteristics of modern authentic scientific research (Chinn & Malhotra, 2002; Falk & Yarden, 2009; Gelbart & Yarden, 2011), namely the way scientific knowledge is created and evaluated in the life sciences today. In this view, the assessment tool represents the teachers' appropriation of the new curriculum in bioinformatics, through adoption of its authentic scientific research characteristics, and through expansion of its roots to the 'traditional' curriculum. Although these aspects of authentic and modern scientific research, namely the application of conditional knowledge as well as coordination between biological and bioinformatics approaches respectively, were part of the training program, the teachers intentionally adopted them as central to the design of the assessment tool. Evidently, these features are more abundant in the assessment tool as compared to the LE activities. The assessment tool developed by the teachers was in accordance with the goals of the bioinformatics curriculum; at the same time it comprehensively integrated and presented unique features of the bioinformatics field, which is rich in diverse procedural skills coupled with the declarative knowledge and analytical thinking required to understand and master bioinformatics approaches and applications (Wefer & Anderson, 2008).

The design and development of an assessment tool for an innovative curriculum by teachers can serve as an appropriate means of linking and integrating contemporary and pioneering materials into existing scientific curricula. It can also support teachers' association with the new curriculum and expand their knowledge. Since the process of assessment tool development was central to the teachers program, it probably had a substantial impact on teachers' decision to adapt the new curriculum in bioinformatics and instruct their own students toward the matriculation examination. It may also have affected their orientation toward educational reforms and professional development programs, as one teacher noted "I'm interested in being part of future programs of developing [educational] initiatives…from the perspective of my standards, I always want to be at the forefront, I do not want to lag behind…this is how I see myself!" (Teacher #4). Thus, it is recommended that key steps of the design and development of assessment tool or learning materials be integrated into professional development programs or training workshops for teachers.

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